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An Indirect Evaluation of the Reactivity of Inertinites in Western Canadian Coking Coals.

- Final Report -

June 1984.

Prepared For

Canada Centre for Mineral & Energy Technology

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June 20, 1984.

Reference:- 1SQ83-00061

Dr. John T. Price,
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555 Booth Street,
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SUBJECT: Unsolicited Proposal on Reactivity of Inertinites in Western Canadian Coking Coal.

---- Final Report ----

Dear John:

We are pleased to provide you with copies of our Final Report on the unsolicited proposal, **An Indirect Evaluation of the Reactivity of Inertinites in Western Canadian Coking Coals.**

We wish to acknowledge the support provided by the Department of Supply & Services and the Department of Energy Mines & Resources, which both enabled this research to be done, and provided us with financial stability during particularly difficult economic times.

Yours very truly,
David E. Pearson & Associates Ltd.,

David E. Pearson, Ph.D., P.Eng.

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1.0. SUMMARY

The work described in this report is concerned with the problem of being unable to confidently predict the quality of many Western Canadian coking coals using present techniques of coal petrography.

Coal petrography is the science of coal microscopy, and involves the examination of coal particles under reflected-light. The observed microscopic particles, called macerals, are analogous to the minerals that comprise other rocks. Three principal types of macerals are recognized, and of these, exinite and vitrinite are reactive in carbonization, together with a portion of semifusinite which belongs to the third group, the Inertinites.

In a typical Western Canadian coking coal, as much as one half of the macerals are semifusinite, and so it is important to know, with some assurance, how much of this material is reactive. The distinction is of more than academic interest, the amount of reactive semifusinite can contribute to a very good exportable coking coal, or render the coal mediocre and of limited commercial value. Moreover, it is too expensive to test every coal sample in a coke oven, and more often than not, only small samples are available from drill core. A reliable petrographic procedure is very desirable.

At present, estimates of the proportion of reactive semifusinites are based on the assumption of a fixed level of reactivity. These values however, are often in error.

The work described here offers a unique solution to the problem of reactivity of Inertinites (semifusinites) in Western Canadian coals. On a suite of 76 samples, which had previously been carbonized and for which coke strength data were available, $R_o max$, a parameter of rank, was determined. Two new parameters, **Calculated Inerts**, and the **Reactive Cutoff**, were computed for each of these samples. Calculated Inerts is the theoretical quantity of Inertinite macerals & mineral-matter required to produce the determined coke strength, whereas the Reactive Cutoff is the random reflectance value separating reactive- from inert-macerals, that will provide this required level of Calculated Inerts.

It was found that for the range of vitrinite reflectances studied (0.89% to 1.63%), there is a strongly correlative

linear relationship between $R_o$max and the Reactive Cutoff (R^2=0.92). This implies that for any coal, the Reactive Cutoff can be calculated, and the distinction between Reactive- and Inert macerals can be made wholly on the basis of random reflectance.

Among the sample suite, it was found that the proportion of reactive semifusinite required to correctly predict coke strength varied between 12% and 43%. It is shown how coke-strength calculation-techniques that require a fixed semifusinite reactivity are unlikely to prove universally applicable among semifusinite-rich coals. It is further explained why such a technique will work, with various levels of success, only among semifusinite-poor coals.

By using the Reactive Cutoff method, described in this report, to distinguish between Inert- and Reactive macerals during coal-type analysis, it is no longer necessary to be able to recognize semifusinite macerals. Nor is it important to know what proportion of semifusinites are reactive. Initial indications are that this method of coal-type analysis is likely to be universally applicable, and will generate coke strength predictions with a greater degree of assurance than was previously possible.

The results of this study should prove of considerable benefit to the export coal industry of western Canada, as well as the Canadian steel industry.

2.0. INTRODUCTION TO THE PROBLEM

2.1. Inert & Reactive Macerals.

Coal is composed of microscopically recognizable constituents, called **macerals**, which differ from one another in both form and reflectance. Macerals are coalified plant material, and are analogous to minerals in inorganic rocks. There are three principal groups of macerals, which are, in increasing order of carbon content and reflectance, **Exinite, Vitrinite** and **Inertinite.**

By carefully counting the various types of macerals present in a prepared sample of crushed coal, a coal petrographer (or coal microscopist), can specify the coal-type, or **petrographic composition**, of a coal in terms of these maceral groups. The petrographer also measures the maximum incident-light reflectance of the most abundant maceral, vitrinite, and this is the value that is used to describe the **rank** of a coal. These two parameters, rank and petrographic composition, uniquely define any coal in the world.

Macerals are further classified as **Inert** or **Reactive**, depending upon the way they respond in carbonization. Carbonization is the heating of coal in the absence of air to produce coke. During this process, Vitrinite and Exinite melt and become fluid, whereas Inertinites, for the most part, remain inert, and form the skeletal framework of the resultant coke. It is known, for example, that the vitrinites of coking-coals melt during carbonization, whereas **Fusinite**, an Inertinite maceral with a much higher reflectance than vitrinite, never melts. Whether or not a maceral melts is therefore related to its' reflectance and carbon content.

2.2. The Semifusinite Problem - the Reactivity of Inertinites.

An important maceral that is intermediate in reflectance between vitrinite and fusinite is called **semifusinite.** It belongs to the Inertinite group of macerals. Despite their classification however, semifusinites which have a similar reflectance to the accompanying vitrinite, are known to melt, and be reactive in carbonization, whereas others that are highly reflecting, are by contrast inert in the coke-making process.

Coals from Nova Scotia, like those from the eastern United States, typically possess very large proportions of Reactive macerals (>80%), with only small amounts (<5%) of semifusinite. In contrast, many western Canadian coals have 50% semifusinite, or more, and less than 40% Vitrinite. The amount of semifusinite that is reactive in coals from Nova Scotia or the eastern U.S. is therefore insignificant, but in western Canadian coals, the contribution it makes to the Reactives is crucial, being the difference between a good and a mediocre coking coal.

The problem is, how can reactive semifusinite be distinguished from inert semifusinite using the reflected-light microscope? This is a problem that has confronted coal petrographers for many years, and is one that deserves a solution, if only for the practical benefits that would ensue.

Prior to this work, we theorized that there exists for each coal a reflectance value, the **Reactive Cutoff**, above which all macerals are inert, and below which all macerals are reactive. The location of this value is between the reflectances of vitrinite and fusinite, and falls within the reflectance range of the semifusinite population. Thus, the proportion of reactive semifusinite is believed to be unique for each coal, and is related to the distribution of the semifusinite population, and to the rank of the coal. The work described in this report was designed to test this hypothesis.

2.3. Current procedures for dealing with Semifusinite.

The prediction of tumbler-strength of metallurgical coke by the microscopic examination of a candidate coal is a procedure used by virtually every steelmaker and metallurgical coal producer in the world today. Canadian coal petrographers assign proportions of semifusinite to inert or reactive categories **not on the basis of a reflectance cut-off, but arbitrarily, based on the total amount of semifusinite** in the coal sample. For example, among Nova Scotian and eastern U.S. coals, with total semifusinite contents generally close to 10%, only one-third is regarded as reactive, (method of Schapiro, Gray & Eusner, 1961). By contrast, for western Canadian coals, half of the semifusinite is regarded as reactive in coals with more than 20% total semifusinite (method of Carr & Jorgensen, 1975). Also, as a further departure from the

Schapiro et al technique, CANMET Laboratories use different Optimum Inert Ratios for western Canadian coals. These ratios are constants used in the calculations to derive the coke strength.

3.0. SAMPLES

Seventy six samples were provided by three coal companies for use in this study. Of these, three samples were discarded because no analytical data were available for the coals; two samples had in excess of 9% oxidized grains, which added a further variable that we did not wish to address at this time, one sample was mislaid, and nine samples were removed from the suite for reasons discussed below. Thus, of the original 76 samples, 61 were used in the study. The provenance of these samples is listed below:-

Quintette Coal Ltd., Tumbler Ridge, 32 samples.

Crows Nest Resources Ltd., Sparwood, 20 samples.

Fording Coal Ltd., Elkford, 9 samples.

After the main suite had been examined, six further samples were provided by CANMET to evaluate the method and to determine whether it is applicable to Appalachian coals. Of these six coals, four were of Pennsylvanian-age, the two remaining were Cretaceous-age coals from Western Canada. CANMET considered one of the samples to be oxidized.

4.0. METHOD OF STUDY

Five steps were involved in deriving the raw data for each sample.

Step 1 - Vitrinite Reflectance Analysis.

The polarized incident-light reflectance of Vitrinite was measured on each of one hundred grains. These values are the maximum reflectance, obtained by stage rotation ($R_o max$), measured at 546 nm. A computer-drawn histogram, histogram-statistics and the vitrinite-type distribution were prepared for each sample.

The $R_o$max of each sample is recorded in Table 1.

Step 2 - Determine Calculated Inerts in carbonized sample.

This is a crucial step in the method, and is made possible by the use of microcomputers. The program, COKE STABILITY, was used to determine the actual proportion of inerts in the carbonization charge of each sample.

Normally, the coke stability index is computed from coal petrographic observations, using two sets of data input:-

1. **Vitrinite-type** distribution, or the spread of the vitrinite population, obtained from the vitrinite histogram, for example,

V-11	9.5%
V-12	39.0%
V-13	46.5%
V-14	0.5%

2. **Total Inert** content (Inertinite macerals + mineral-matter); and **Strength Factors** for each vitrinite-type. The latter are contained in standard tables, and are a function of Total Inerts and Vitrinite-type.

These data are used to derive two parameters, the **Balance Index** and the **Strength Index**, from which standard tables are used to predict the stability index.

In the case of the samples examined in this study, the actual Coke Stability and Vitrinite-type distribution are already known. The unknowns are Total Inerts, and Strength Factors. To solve the problem, COKE STABILITY is rerun, several times, with different values for Total Inerts and Strength Factors, until the derived Balance Index and Strength Index, predict the same value for the Coke Stability Index as was actually determined at the CANMET Laboratories.

In this way, a specific value for Total Inerts, the **Calculated Inerts**, was determined, which is the level of inerts required to correctly predict the actual coke stability for each sample, **as charged**, to the coke oven.

The value of Calculated Inerts, for each sample, is shown in Table 1.

Step 3 - Produce Reflectogram on 1000 macerals.

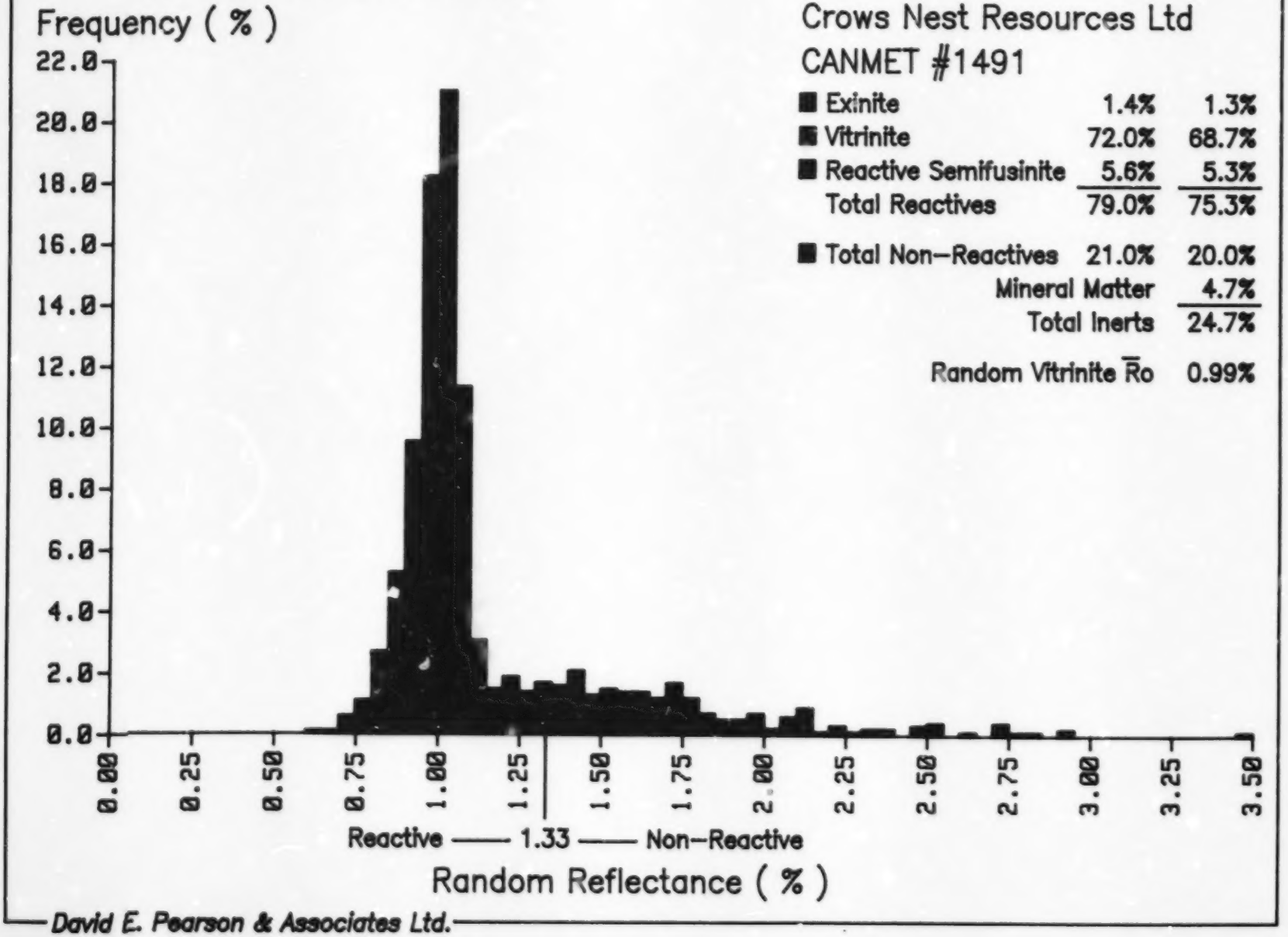
Maceral analysis was performed on each coal in the normal way, classifying the macerals by group, that is, Exinite, Vitrinite or Inertinite. No attempt was made to assess the reactivity of the semifusinites in the Inertinite group. At the same time, the R_o random reflectance of each maceral was also measured, with the field diaphragm closed, and microscope polarizer in place, and stored in the computer. This measurement was made on one thousand individual macerals.

The program, REFLECTOGRAM, was then used to process these data, to determine the random vitrinite reflectance, and to produce a reflectogram of one thousand reflectance values on each sample. The program requires input of ash and sulphur values (dry basis), so that corrections to the mineral-matter-free coal can be effected electronically.

Figure 1, shows a typical computer-generated reflectogram. The green area on the reflectogram represents Exinite; the red area represents Vitrinite; and the blue area represents Inertinite. The relative position of the reflectance cutoff can be moved. In the figure a value of 1.33% was used. The program then calculates the proportion of inertinites to the left of this line and labels them **Reactive Inertinites.** Similarly it computes the proportion of **Non-Reactive Inertinites.** In the last column at the top right of the figure, the raw maceral data are corrected for the amount of mineral-matter in the coal, and the value for Total Inerts (Inertinite macerals + mineral-matter) is computed.

Figure 1

REFLECTOGRAM



Crows Nest Resources Ltd

CANMET #1491

Exinite	1.4%	1.3%
Vitrinite	72.0%	68.7%
Reactive Semifusinite	5.6%	5.3%
Total Reactives	79.0%	75.3%
Total Non–Reactives	21.0%	20.0%
Mineral Matter		4.7%
Total Inerts		24.7%
Random Vitrinite $\overline{R}o$		0.99%

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For each sample, the REFLECTOGRAM program was rerun several times with different values for the reflectance cutoff until the value for Total Inerts was the same as the Calculated Inerts determined in Step 2 above. In this way, a reflectance cutoff value was determined for the Inertinite macerals in each sample, which would allow the prediction of the actual coke stability. This reflectance value is called the **Reactive Cutoff**, because it is the reflectance cutoff required to produce the Calculated Inerts.

The Reactive Cutoff, is shown for each sample in Table 1.

Step 4 - Determine Maceral Composition.

The maceral data obtained during the reflectogram analysis were then reviewed. The reactive maceral component is the sum of Vitrinite, Exinite plus the reactive Inertinites (a portion of the semifusinite). During the maceral analysis, no attempt was made to assign reactivity to the Inertinites, but on the basis of the reactive cutoff described in Step 3 above, the actual proportion of Reactive Inertinites (semifusinites) can be computed from the total semifusinite population.

This exercise was done for each of the samples examined and the results are listed in Table 1.

The percentage of reactive semifusinite relative to the total semifusinite population is also shown for each sample in Table 1.

4.1. Rejected Samples.

There are two unstated assumption inherent in the petrographic method, and to this technique in particular. These are:-

1. That each pellet is truly representative of the coal that was carbonized.

2. That the petrography of each pellet can correctly predict the coke strength of

the carbonized coal.

Despite repeated analyses, nine samples did not meet these criteria, and were rejected from the suite. These samples are identified in Table 1 with an asterisk. An example of a rejected sample is described below.

CANMET #1491 is a coal with a vitrinite reflectance of 1.10% $R_o$max, 8.6% ash and 0.33% sulphur. Coke prepared from this coal had a tumbler stability of 39.3. Calculations show that this sample required either 43.5% or 9.00% Total Inerts to produce a coke of this strength (Figures 2A & 2B), yet the reflectogram of the coal reveals combined reactives of 75.3%, and Inerts of 24.6%! (Figure 1). Thus, in the carbonized sample, either 18.9% of the reactives were actually inert (for which there is no visible evidence), or 15.6% excess Inertinite is present in the petrographic pellet. Alternatively, coke-oven conditions were abnormal, and a coal with a potential coke strength of 58.9 attained only a value of 39.3. Whatever the reason, the coal fails to pass the two criteria described above and is relegated to the category of Rejected Samples.

Inevitably, some will argue that this bias in sample selection nullifies any conclusions that may be reached on the basis of this study. We would argue however, that the two criteria we have applied are so fundamental to coal petrography, and tacitly understood by all who use coal petrography to routinely predict coke strength of coal samples, that by not applying them we may have hidden from view the very relationships that we sought to find.

5.0. RESULTS

The results of the various petrographic analyses are shown in Table 1.

5.1. Rank & Type of Samples.

Figure 3, shows the petrographic composition of the 61 samples, expressed as a function of Vitrinite Reflectance and Total Inerts. With the exception of four samples, all are typical Western Canadian coking coals, with vitrinite reflectances between 1.0% and 1.7%, and Total Inerts between 25-50%. They conform to the G3 & G4 (Balmer and Moura) groups of coking coals as defined by Pearson, 1980.

Coke Stability Index Calculation

Sample # CANMET 1491

Total Inerts = 43.50

100 - TI / 100 = 0.56

Vitrinite Types	%	Prorated Reactives	Optimum Ratio	PR/OR	Strength Factors	PR*SF
V-4		0.00	4.30	0.00	1.04	0.00
V-5		0.00	3.80	0.00	1.23	0.00
V-6		0.00	3.50	0.00	1.45	0.00
V-7		0.00	3.10	0.00	1.69	0.00
V-8		0.00	2.80	0.00	2.12	0.00
V-9	3.00	1.69	2.60	0.65	3.23	5.47
V-10	42.00	23.73	2.40	9.89	3.49	82.82
V-11	51.00	28.81	2.70	10.67	4.11	118.43
V-12	3.00	1.69	3.20	0.53	4.35	7.37
V-13	1.00	0.56	4.00	0.14	5.47	3.09
V-14		0.00	5.20	0.00	6.45	0.00
V-15		0.00	7.00	0.00	6.62	0.00
V-16		0.00	9.50	0.00	6.79	0.00
V-17		0.00	12.30	0.00	6.96	0.00
V-18		0.00	14.80	0.00	7.08	0.00
V-19		0.00	17.10	0.00	7.24	0.00
V-20		0.00	19.30	0.00	4.97	0.00

Optimum Inert Index = 21.88

Optimum Strength Index = 217.19

Composition Balance Index = 1.99
Strength Index = 3.84

Coke Stability Index = 39.00

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Figure 2A A computer printout from the program COKESTABILITY, showing how sample CANMET #1491 required 43.5 % Total Inerts to generate a Composition Balance Index of 1.99, and a Strength Index of 3.84, which together predict a Coke Stability Index of 39.0

Coke Stability Index Calculation

Sample # CANMET 1491

Total Inerts = 9.00

100 - TI / 100 = 0.91

Vitrinite Types	%	Prorated Reactives	Optimum Ratio	PR/OR	Strength Factors	PR*SF
V-4		0.00	4.30	0.00	2.31	0.00
V-5		0.00	3.80	0.00	2.40	0.00
V-6		0.00	3.50	0.00	2.52	0.00
V-7		0.00	3.10	0.00	2.62	0.00
V-8		0.00	2.80	0.00	2.73	0.00
V-9	3.00	2.73	2.60	1.05	3.20	8.74
V-10	42.00	38.22	2.40	15.93	3.47	132.62
V-11	51.00	46.41	2.70	17.19	4.22	195.85
V-12	3.00	2.73	3.20	0.85	4.49	12.26
V-13	1.00	0.91	4.00	0.23	5.75	5.23
V-14		0.00	5.20	0.00	7.05	0.00
V-15		0.00	7.00	0.00	7.24	0.00
V-16		0.00	9.50	0.00	7.39	0.00
V-17		0.00	12.30	0.00	7.55	0.00
V-18		0.00	14.80	0.00	7.69	0.00
V-19		0.00	17.10	0.00	7.82	0.00
V-20		0.00	19.30	0.00	6.74	0.00

Optimum Inert Index = 35.24

Optimum Strength Index = 354.70

Composition Balance Index = 0.26
Strength Index = 3.90

Coke Stability Index = 39.00

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Figure 2B A computer printout from the program COKESTABILITY, showing how sample CANMET #1491 required 9.0% Total Inerts to generate a Composition Balance Index of 0.26, and a Strength Index of 3.90, which together predict a Coke Stability Index of 39.0

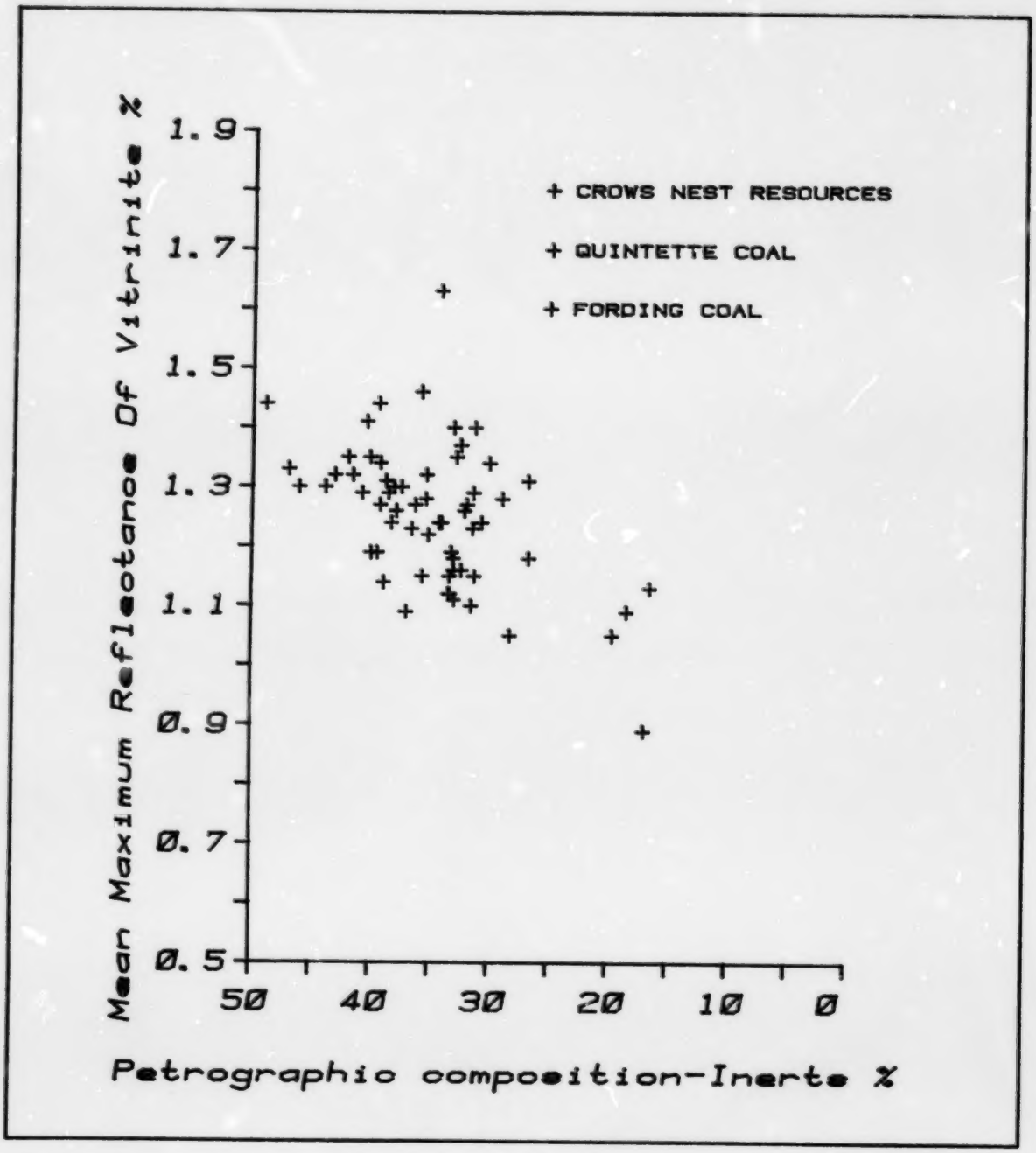

Figure 3 Petrographic composition of the 61 coals used in the study.

Table 1

CANMET Sample #	267	278	284	1005	1025	1026	1070
Reflectance Analysis							
V-9...					1		
V-10..	1	2			52	11	
V-11..	2	6	2		43	69	1
V-12..	39	43	8	2	4	18	4
V-13..	50	44	52	49		1	27
V-14..	8	5	36	43		1	64
V-15..			2	5			4
V-16..				1			
$R_o$max.	1.31	1.29	1.37	1.40	1.09	1.16	1.41
R_o random	1.20	1.13	1.20	1.27	0.97	1.07	1.30
Maceral Analysis							
Vitrinite	68.1	59.6	55.1	55.2	55.8	60.7	48.9
Exinite	0.0	0.0	0.0	0.0	2.0	0.1	0.0
Reactive SF	5.1	9.0	12.4	13.5	5.2	6.1	10.7
Total SF	22.1	32.1	35.8	35.1	29.9	28.9	40.3
(% SF Reactivity)	23.0	28.0	34.6	38.5	17.4	21.1	26.6
Inert SF	17.0	23.1	23.4	21.6	24.7	22.8	29.6
Macrinite	0.8	1.0	0.4	0.5	1.2	0.4	0.6
Inertodet.	2.2	2.7	2.5	1.6	4.0	2.3	2.8
Fusinite	2.9	1.5	2.6	3.2	3.1	3.1	3.1
Min. Mat. (Parr)	3.9	3.1	3.6	4.4	4.0	4.5	4.3
Total Inerts	26.8	31.4	32.5	31.3	37.0	33.1	40.4
Calculated Inerts	26.7	31.0	32.0	31.0	37.0	33.5	40.5
Reactive Cutoff	1.55	1.52	1.60	1.64	1.31	1.39	1.62
Schapiro Inerts	24.5	29.7	33.0	33.1	32.2	29.6	37.7
Pearson Inerts	27.9	31.3	32.5	32.4	37.0	34.1	39.9
Coke Strength Indices							
Tumbler Stability	63.0	60.0	59.5	60.2	49.5	55.4	52.9
Schapiro Method	64.5	60.7	58.8	59.0	54.5	60.0	55.3
- difference	+1.5	+0.7	-0.7	-1.2	+5.0	+4.6	+2.4
Pearson Method	62.1	60.0	59.3	59.5	49.5	54.7	53.2
- difference	-0.9	00.0	-0.2	-0.7	00.0	-0.7	+0.3

Table 1, continued

CANMET Sample #	1072	1073	1080	1081	1082	1371	1372
Reflectance Analysis							
V-9...			1				2
V-10..			8	1	1		40
V-11..			66	26	9		52
V-12..		3	22	52	58		4
V-13..	13	42	3	21	31		2
V-14..	61	51			1	1	
V-15..	25	4				25	
V-16..	1					63	
V-17..						10	
V-18..						1	
$R_o$max.	1.46	1.40	1.16	1.24	1.27	1.63	1.11
R_o random	1.31	1.26	1.05	1.12	1.17	1.49	1.02
Maceral Analysis							
Vitrinite	56.9	58.7	60.3	59.4	52.3	55.8	58.0
Exinite	0.0	0.0	0.6	0.0	0.0	0.0	0.6
Reactive SF	7.3	8.2	6.7	9.9	11.4	10.0	8.4
Total SF	32.5	30.2	27.8	31.7	37.1	32.6	31.6
(% SF Reactivity)	22.5	27.2	24.1	31.2	30.7	30.7	26.6
Inert SF	25.2	22.0	21.1	21.8	25.7	22.6	23.2
Macrinite	1.0	1.5	1.2	0.4	0.1	0.2	0.6
Inertodet.	2.3	3.5	2.7	1.9	3.3	3.6	1.6
Fusinite	3.0	2.2	3.1	2.7	3.0	3.0	4.1
Min. Mat. (Parr)	4.3	3.9	4.3	3.9	4.2	4.8	3.5
Total Inerts	35.8	33.1	32.4	30.7	36.3	34.2	33.0
Calculated Inerts	36.3	33.0	32.7	31.0	36.5	34.7	32.0
Reactive Cutoff	1.65	1.62	1.38	1.50	1.50	1.81	1.38
Schapiro Inerts	32.3	31.2	29.8	30.0	35.3	33.3	30.9
Pearson Inerts	35.3	33.1	32.4	32.2	36.6	32.2	35.0
Coke Strength Indices							
Tumbler Stability	55.2	59.3	56.6	59.2	53.5	43.2	55.4
Schapiro Method	58.8	60.5	60.1	60.5	54.5	46.0	56.8
- difference	+3.3	+1.2	+3.5	+1.3	+1.0	+2.8	+1.4
Pearson Method	55.7	58.7	57.0	57.7	52.8	48.2	52.8
- difference	+0.5	+0.5	-0.4	-1.5	-0.7	+5.0	-2.6

Table 1, continued

CANMET Sample #	1373	1374	1500	1501	1502*	1503*	1504
Reflectance Analysis							
V-10..	22	2	4	1			
V-11..	53	29	51	5	11	9	5
V-12..	23	64	44	56	56	58	44
V-13..	2	5		38	32	30	46
V-14..			1			3	5
V-15..					1		
$R_o$max.	1.15	1.22	1.19	1.28	1.27	1.27	1.30
R_o random	1.03	1.07	1.03	1.11	1.12	1.11	1.18
Maceral Analysis							
Vitrinite	58.2	54.1	48.7	53.5	57.5	53.7	51.4
Exinite	0.1	0.3	0.7	0.4	0.1	0.4	0.1
Reactive SF	8.3	10.4	10.6	10.7	5.7	2.1	10.4
Total SF	32.2	37.7	43.7	38.8	36.3	37.0	40.5
(% SF Reactivity)	25.8	27.6	24.3	27.6	15.7	5.7	25.7
Inert SF	23.9	27.3	33.1	28.1	30.6	34.9	30.1
Macrinite	1.2	0.5	0.4	0.7	0.2	0.4	0.6
Inertodet.	2.1	1.4	1.0	1.0	0.7	2.1	1.3
Fusinite	2.4	3.3	1.4	0.4	1.2	2.1	1.7
Min. Mat. (Parr)	3.8	2.7	4.1	4.9	4.0	4.3	4.3
Other				0.3			0.1
Total Inerts	33.4	35.2	40.0	35.4	36.7	43.8	38.1
Calculated Inerts	33.0	36.0	40.0	36.0	37.0	44.0	37.5
Reactive Cutoff	1.38	1.40	1.43	1.51	1.44	1.20	1.51
Schapiro Inerts	30.9	33.0	36.0	33.2	30.3	33.6	35.0
Pearson Inerts	33.8	33.2	41.2	36.4	35.5	37.7	37.5
Coke Strength Indices							
Tumbler Stability	55.3	52.6	47.7	54.0	52.4	44.4	53.6
Schapiro Method	57.8	55.8	52.7	57.0	60.3	56.5	56.0
- difference	+2.5	+3.2	+5.0	+3.0	+7.9	+12.1	+2.4
Pearson Method	54.8	55.5	45.5	53.3	53.8	52.0	52.8
- difference	-0.5	+2.9	-2.2	-0.7	+1.4	+7.6	-0.8

Table 1, continued

CANMET Sample #	1505	1506	1507	1604	1605	1698	1699
Reflectance Analysis							
V-9...							1
V-10..	2		1	20	18.5	7	13.5
V-11..	21	19	12	70	59	52	72
V-12..	59	65	58	10	22.5	41	13
V-13..	17	16	28				0.5
V-14..	1		1				
$R_o$max.	1.24	1.24	1.26	1.14	1.15	1.18	1.15
R_o random	1.11	1.18	1.15	1.04	1.06	1.09	1.05
Maceral Analysis							
Vitrinite	54.6	52.2	51.7	48.8	51.2	51.2	54.7
Exinite	0.2	0.0	0.0	0.7	0.2	2.6	1.4
Reactive SF	11.1	9.5	10.4	11.6	12.9	13.1	12.6
Total SF	37.6	39.2	40.1	42.2	37.1	36.4	34.6
(% SF Reactivity)	29.5	24.2	25.9	27.5	34.8	35.9	30.9
Inert SF	26.5	29.7	29.7	30.6	24.2	23.3	22.0
Macrinite	0.5	0.2	0.2	0.8	0.8	1.2	1.4
Inertodet.	1.5	3.0	2.2	1.1	1.8	1.1	0.9
Fusinite	1.3	1.3	2.1	1.6	3.7	2.6	2.2
Other				0.5	1.3		
Min. Mat. (Parr)	4.3	4.1	3.7	4.3	3.9	4.9	4.8
Total Inerts	34.1	38.3	37.9	38.9	35.7	33.1	31.3
Calculated Inerts	34.0	38.3	38.0	37.5	35.5	33.0	31.5
Reactive Cutoff	1.46	1.49	1.45	1.37	1.41	1.47	1.38
Schapiro Inerts	32.7	34.7	34.9	36.4	36.2	34.1	32.4
Pearson Inerts	34.1	40.5	36.5	39.7	37.0	33.3	31.7
Coke Strength Indices							
Tumbler Stability	55.4	50.6	51.8	50.9	52.4	55.9	57.1
Schapiro Method	57.0	54.5	54.8	51.8	52.0	54.5	56.5
- difference	+1.6	+3.9	+3.0	+0.9	-0.4	-1.4	-0.6
Pearson Method	55.5	47.2	53.0	47.3	51.0	55.5	57.1
- difference	+0.1	-3.4	+1.2	-3.6	-1.4	-0.4	00.0

Table 1, continued

CANMET Sample #	2005	2006	2007	2008	2009	2012*	2042*
Reflectance Analysis							
V-10..	1						
V-11..	15	1			3	1	5
V-12..	75	19	1		67	25	62
V-13..	9	60	19	20	29	60	32
V-14..		20	64	70	1	14	1
V-15..			16	10			
$R_o$max.	1.23	1.34	1.44	1.44	1.28	1.33	1.28
R_o random	1.15	1.17	1.31	1.34	1.14	1.19	1.14
Maceral Analysis							
Vitrinite	53.6	64.0	44.6	33.5	65.0	54.9	60.3
Exinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reactive SF	9.8	5.9	16.0	17.6	6.0	3.3	4.3
Total SF	36.2	27.3	46.9	55.6	26.4	35.6	26.9
(% SF Reactivity)	27.0	21.6	34.1	31.7	22.7	9.26	15.9
Inert SF	26.4	21.4	30.9	38.0	20.4	32.3	22.6
Macrinite	1.1	0.8	1.1	0.4	0.2	0.0	0.8
Inertodet.	0.7	1.1	1.2	2.5	1.9	2.2	2.8
Fusinite	2.2	2.7	2.2	2.5	2.1	2.2	3.7
Other	1.8		0.2				
Min. Mat. (Parr)	4.4	4.1	3.8	5.5	4.4	5.1	5.5
Total Inerts	36.6	30.1	39.4	48.9	29.0	41.8	35.4
Calculated Inerts	36.5	30.5	39.8	49.0	28.5	41.5	35.0
Reactive Cutoff	1.46	1.54	1.66	1.67	1.51	1.45	1.40
Schapiro Inerts	34.3	26.9	39.8	47.9	26.2	33.2	30.7
Pearson Inerts	36.9	29.8	39.4	49.9	29.3	38.7	32.7
Coke Strength Indices							
Tumbler Stability	52.0	60.7	53.0	37.6	61.1	50.9	54.9
Schapiro Method	54.5	63.2	53.2	40.5	62.8	58.5	60.2
- difference	+2.5	+2.5	+0.2	+2.9	+1.7	+7.6	+5.3
Pearson Method	52.0	52.2	53.2	37.2	60.5	53.2	57.2
- difference	00.0	-8.5	+0.2	-0.4	-0.6	+2.3	+2.3

Table 1, continued

CANMET Sample #	2043	416	417	993	1068	1069	2150
Reflectance Analysis							
V-8...				57			
V-9...			1	43		14	
V-10..			23		46	75	
V-11..	18	34	70		54	11	2
V-12..	63	63	6				30
V-13..	19	3					60.5
V-14..							7.5
$R_o$max.	1.24	1.19	1.13	0.89	1.09	1.05	1.32
R_o random	1.15	1.10	1.07	0.84	0.98	0.96	
Maceral Analysis							
Vitrinite	55.9	49.2	76.2	71.9	71.3	74.8	44.2
Exinite	0.1	0.0	1.2	5.1	0.7	1.5	0.2
Reactive SF	9.7	11.3	6.0	6.0	9.5	4.0	12.5
Total SF	32.1	42.5	16.2	17.4	22.6	15.9	39.6
(% SF Reactivity)	30.2	26.6	37.0	34.5	42.0	25.1	31.6
Inert SF	22.4	31.2	10.2	11.4	13.1	11.4	27.1
Macrinite	1.4	1.0	0.3	0.2	0.6	0.6	2.4
Inertodet.	1.1	0.9	0.8	0.9	0.2	1.2	2.4
Fusinite	2.5	2.2	0.8	0.6	0.4	1.9	5.7
Other	2.0						
Min. Mat. (Parr)	4.9	4.2	4.5	3.9	4.2	4.6	5.5
Total Inerts	34.3	39.5	16.6	17.0	18.5	19.7	43.1
Calculated Inerts	35.0	39.0	16.0	17.5	18.7	19.7	42.0
Reactive Cutoff	1.45	1.42	1.41	1.11	1.30	1.20	1.53
Schapiro Inerts	33.3	36.6	17.2	17.2	20.5	18.6	42.4
Pearson Inerts	33.8	39.3	17.7	17.5	18.6	18.1	41.5
Coke Strength Indices							
Tumbler Stability	54.3	48.8	54.4	34.1	54.7	51.9	49.8
Schapiro Method	57.0	52.1	56.1	33.8	56.3	48.0	49.5
- difference	+2.7	+3.3	+1.7	-0.3	+1.6	-3.9	-0.3
Pearson Method	55.5	48.2	56.8	34.2	54.7	47.5	50.3
- difference	+1.2	-0.6	+2.4	+0.1	00.0	-4.4	+0.5

Table 1, continued

CANMET Sample #	2152	2153	2254	2151	M1449
Reflectance Analysis					
V-7...			0.25		
V-8...			0.50		
V-9...			0.75		1
V-10..					0.5
V-11..	1		7.75		4.5
V-12..	33	24	46.25	18	48.5
V-13..	58	72	39.00	72	41.5
V-14..	8	4	5.50	10	4
$R_o$max.	1.31	1.32	1.29	1.34	1.29
R_o random	1.17	1.16	1.14	1.25	
Maceral Analysis					
Vitrinite	47.0	50.1	47.9	44.9	46.1
Exinite	0.0	0.0	0.2	0.0	0.2
Reactive SF	14.2	14.5	11.1	15.8	15.1
Total SF	42.3	41.2	40.3	45.9	41.9
(% SF Reactivity)	33.5	35.2	27.5	15.8	36.0
Inert SF	28.1	26.7	29.2	30.1	26.8
Macrinite	0.5	0.5	1.2	1.0	1.6
Inertodet.	2.3	1.8	2.6	0.9	1.2
Fusinite	2.8	0.9	2.3	2.2	3.3
Min. Mat. (Parr)	5.1	5.5	5.5	5.1	5.4
Total Inerts	38.8	35.4	40.8	39.3	38.6
Calculated Inerts	39.0	35.5	40.8	39.5	38.0
Reactive Cutoff	1.53	1.54	1.49	1.56	1.52
Schapiro Inerts	38.9	36.2	38.5	39.8	39.4
Pearson Inerts	38.8	35.4	40.0	39.3	38.6
Coke Stability Indices					
Tumbler Stability	51.8	55.7	49.1	52.5	50.1
Schapiro Method	52.5	55.2	51.5	52.5	51.0
- difference	+0.7	-0.5	+2.4	00.0	+0.9
Pearson Method	52.5	56.2	50.5	52.7	51.5
- difference	+0.7	+1.0	+1.4	+0.2	+1.4

Table 1, continued

CANMET Sample #	1349	1353	1354	1375	1394*	1395*	1396
Reflectance Analysis							
V-9...						6	
V-10..					18	72	
V-11..		1	4	2	64	22	4
V-12..	33	22	41	15	17		43
V-13..	57	67	48	57	1		48
V-14..	9	9	7	25			5
V-15..	1	1		1			
$R_o$max.	1.32	1.33	1.30	1.35	1.15	1.06	1.30
R_o random	1.14	1.19	1.15	1.19			1.18
Maceral Analysis							
Vitrinite	42.3	39.9	45.6	44.0			43.4
Exinite	0.0	0.0	0.2	0.0			0.3
Reactive SF	16.1	13.1	8.1	15.8			12.4
Total SF	49.5	48.0	44.5	45.6			46.5
(% SF Reactivity)	32.5	27.3	18.2	34.6			26.7
Inert SF	33.4	34.9	36.4	29.8			34.1
Macrinite	0.4	1.7	0.2	1.2			0.2
Inertodet.	1.4	2.1	2.8	1.6			2.8
Fusinite	1.1	3.4	1.7	2.7			2.2
Other Min. Mat. (Parr)	5.3	4.9	5.0	4.9			4.6
Total Inerts	41.6	47.0	46.1	40.2			43.9
Calculated Inerts	42.0	47.0	47.0	40.0	35/13.5	45/9	43.5
Reactive Cutoff	1.53	1.52	1.45	1.60	1/1.63	0.9/1.91	1.52
Schapiro Inerts	41.2	44.1	39.4	40.8			40.8
Pearson Inerts	40.6	45.2	42.9	42.7			43.9
Coke Strength Indices							
Tumbler Stability	49.9	42.7	41.7	52.9	53.0	32.1	46.0
Schapiro Method	50.9	44.5	51.5	51.8			50.5
- difference	+1.0	+1.8	+9.8	-1.1			+4.5
Pearson Method	51.6	45.5	47.5	50.0			45.8
- difference	+1.7	+2.8	+5.8	-2.9			-0.2

Table 1, continued

CANMET Sample #	1451*	1471	1486	1487	1491*	1492*	1515
Reflectance Analysis							
V-9...	1				3		
V-10..	25				42	25	
V-11..	63		6		51	61	13
V-12..	10	13	50	18	3	12	60
V-13..	1	7i	36	64	1	2	25
V-14..		16	8	18			2
$R_o$max.	1.13	1.35	1.30	1.35	1.10	1.14	1.26
R_o random	0.99	1.16	1.14	1.18	0.99	0.99	1.14
Maceral Analysis							
Vitrinite		48.4	48.9	61.4			55.7
Exinite		0.0	0.0	0.0			0.2
Reactive SF		9.6	13.6	5.7			11.9
Total SF		40.8	43.6	30.0			35.9
(% SF Reactivity)		23.5	31.2	19.0			33.1
Inert SF		31.2	30.0	24.3			24.0
Macrinite		0.8	0.3	0.3			0.2
Inertodet.		2.6	0.6	0.4			1.8
Fusinite		2.3	1.5	2.3			0.9
Other				0.1			
Min. Mat. (Parr)		5.1	5.1	5.5			5.3
Total Inerts		42.0	37.5	32.9			32.2
Calc. Inerts	38.3/12	42.5	38.0	33.0	43.5/9	36/13	32.0
Reactive Cutoff	.85/1.79	1.53	1.52	1.53	.85/1.99	1.05/1.72	1.53
Schapiro Inerts		38.0	36.6	28.6			32.1
Pearson Inerts		39.2	37.6	31.3			35.3
Coke Strength Indices							
Tumbler Stability	49.5	50.4	52.2	58.0	39.3	51.9	58.1
Schapiro Method		54.3	53.4	62.1			58.0
- difference		+3.9	+1.2	+4.1			-0.1
Pearson Method		53.2	52.4	60.2			54.2
- difference		+2.8	+0.2	+2.2			+3.9

Table 1, continued

CANMET Sample #	1516*	1565	1582*	1680	1681*	1769	1772*
Reflectance Analysis							
V-8...							2
V-9...	2	14					5
V-10..	49	74	4	26	31	3	50
V-11..	44	12	27	73	63	52	43
V-12..	5		55	1	6	43	
V-13..			12			2	
V-14..			2				
$R_o$max.	1.10	1.05	1.23	1.12	1.12	1.19	1.09
R_o random	0.97	0.94	1.12	1.01	0.96	1.07	0.98
Maceral Analysis							
Vitrinite		65.6		59.9		57.7	
Exinite		3.1		1.7		1.0	
Reactive SF		3.0		5.0		8.0	
Total SF		25.2		31.2		29.6	
(% SF Reactivity)		11.9		16.0		27.0	
Inert SF		22.2		26.2		21.6	
Macrinite		0.6		0.6		1.0	
Inertodet.		1.4		1.7		2.2	
Fusinite		0.8		1.2		3.5	
Other				0.7			
Min. Mat. (Parr)		3.3	4.9	3.0	4.6	5.0	
Total Inerts		28.3		33.4		33.3	
Calculated Inerts	36/15	28.0	24.1	33.5	41.3/10	33.5	38/14
Reactive Cutoff	0.9/1.64	1.20	1.54	1.27	1.18/2.0	1.45	0.8/1.56
Schapiro Inerts		22.9		28.0		31.4	
Pearson Inerts		26.6		31.2		35.2	
Coke Strength Indices							
Tumbler Stability	50.8	54.0	58.0	54.9	44.4	55.7	46.6
Schapiro Method		52.3		59.9		58.3	
- difference		-1.7		+5.0		+2.6	
Pearson Method		54.0		57.1		51.1	
- difference		00.0		+2.2		+4.6	

Table 1, continued

CANMET Sample #	1827	1828	1829	1830	1864	1865*	1941
Reflectance Analysis							
V-9...					1	8	6
V-10..	2	1	2		50	62	27
V-11..	14	62	11	9	45	25	54
V-12..	77	36	56	55	4	4	13
V-13..	7	1	26	34		1	
V-14..			5	2			
$R_o$max.	1.23	1.18	1.27	1.27	1.10	1.07	1.12
R_o random	1.12	1.06	1.16	1.16	0.99		1.03
Maceral Analysis							
Vitrinite	59.0	65.7	40.8	51.6	59.6		61.4
Exinite	0.0	0.3	0.0	0.0	2.2		0.7
Reactive SF	9.5	7.2	19.9	16.4	6.6		4.4
Total SF	32.1	25.4	50.0	38.4	28.9		27.4
(% SF Reactivity)	29.6	28.3	39.8	42.7	22.8		16.1
Inert SF	22.6	18.2	30.1	22.0	22.3		23.0
Macrinite	0.0	0.5	1.2	0.4	0.5		0.6
Inertodet.	0.9	1.0	0.5	2.3	1.5		2.4
Fusinite	2.9	1.7	2.5	1.8	2.2		2.4
Min. Mat. (Parr)	5.1	5.4	5.0	5.5	5.1		5.1
Total Inerts	31.5	26.8	39.3	32.0	31.6		33.5
Calculated Inerts	31.5	27.0	39.0	32.0	31.2	36.8	33.0
Reactive Cutoff	1.44	1.41	1.60	1.53	1.32		1.27
Schapiro Inerts	30.3	25.5	33.3	35.9	28.6		28.8
Pearson Inerts	30.8	26.8	46.7	34.3	31.6		31.6
Coke Stability Indices							
Tumbler Stability	57.6	61.1	50.7	58.5	54.2	48.7	54.8
Schapiro Method	59.3	61.5	56.8	54.5	57.5		58.8
- difference							
Pearson Method	58.9	61.1	40.2	55.8	55.1		56.1
- difference	+1.3	00.0	-10.5	-2.7	+0.9		+1.3

5.2. Reactive Cutoff Values.

5.2.1. Complete Sample Suite

The Reactive Cutoff value, which for each sample is the reflectance that separates reactive- from inert-macerals, increases with vitrinite reflectance throughout the sample suite. Figure 4 shows a plot of Reactive Cutoff versus $R_o$max for the 61 samples studied. The green line in the diagram is the least-square linear regression best-fit through the 61 sample points. The correlation coefficient for this line is 0.92.

The slope of this line is given by the equation:-

Reactive Cutoff Value R_o (%) = $0.987(R_o\text{max}) + 0.236$

5.2.2. Quintette Samples

The correlation of Reactive Cutoff with vitrinite reflectance for the Quintette sample suite is shown in Figure 5. The green line shows the least square linear regression best-fit through the 32 data points. The correlation coefficient for this line is 0.96.

The slope of this line is given by the equation:-

Reactive Cutoff Value R_o (%) = $0.907(R_o\text{max}) + 0.343$

5.2.3. Fording Samples

Figure 6 shows the correlation of Reactive Cutoff with vitrinite reflectance for the sample suite from Fording Coal. Again, the green line shows the least square linear regression best-fit line through the data points. The correlation coefficient for the line is 0.96.

The slope of the line is given by the equation:-

Reactive Cutoff Value R_o (%) = $1.029(R_o\text{max}) + 0.186$

5.2.4. Crows Nest Samples

The correlation of vitrinite reflectance with the Reactive Cutoff for the sample suite from Crows Nest Resources is shown in Figure 7. The green line shows the least squares regression best-fit through the data points. The

Figure 4

Correlation Romax Vs. Cutoff

Complete 61-Sample Suite

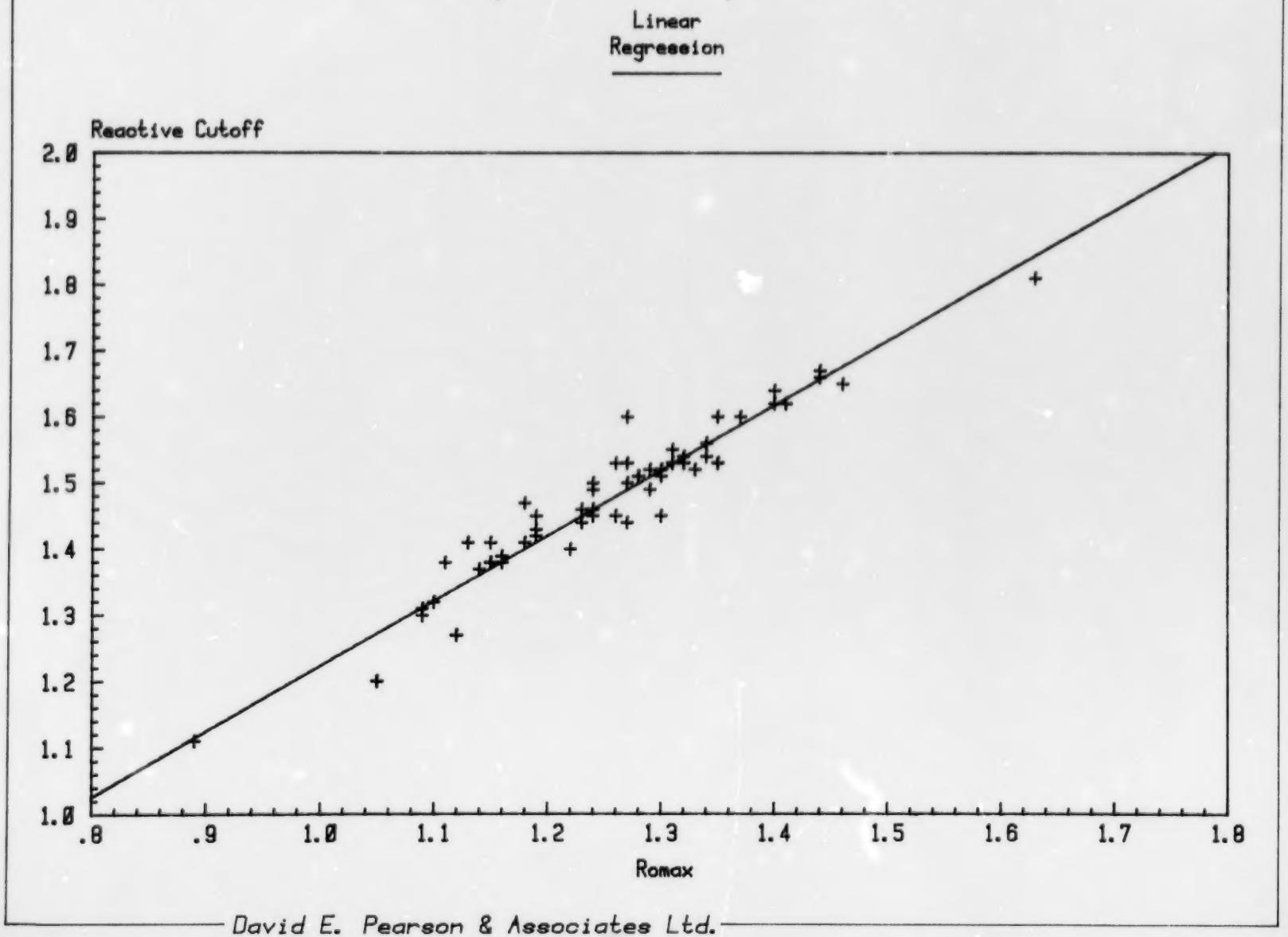

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Figure 5

Correlation Romax Vs. Cutoff

Quintette Samples

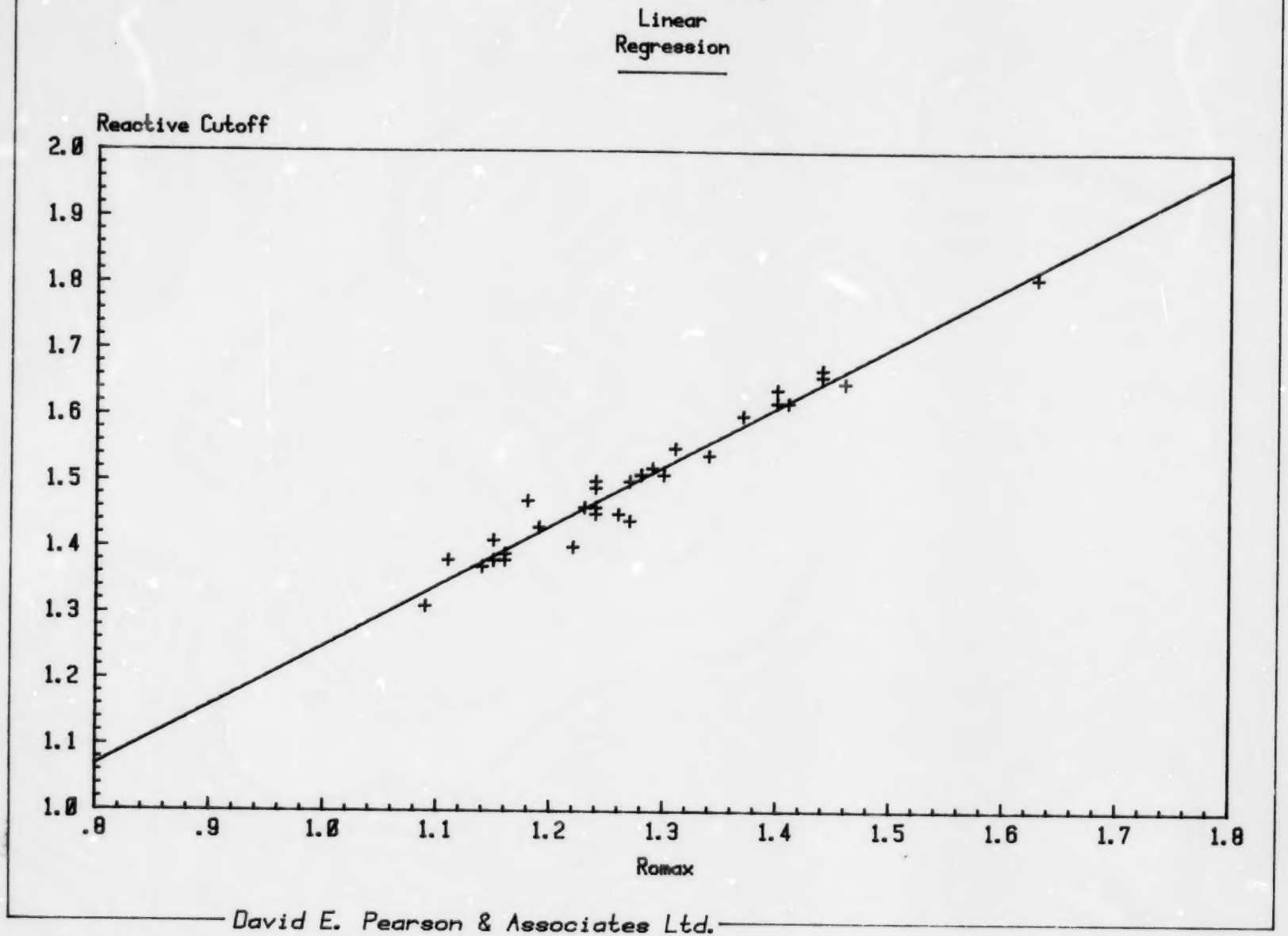

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Figure 6

Correlation Romax Vs. Cutoff

Fording Samples

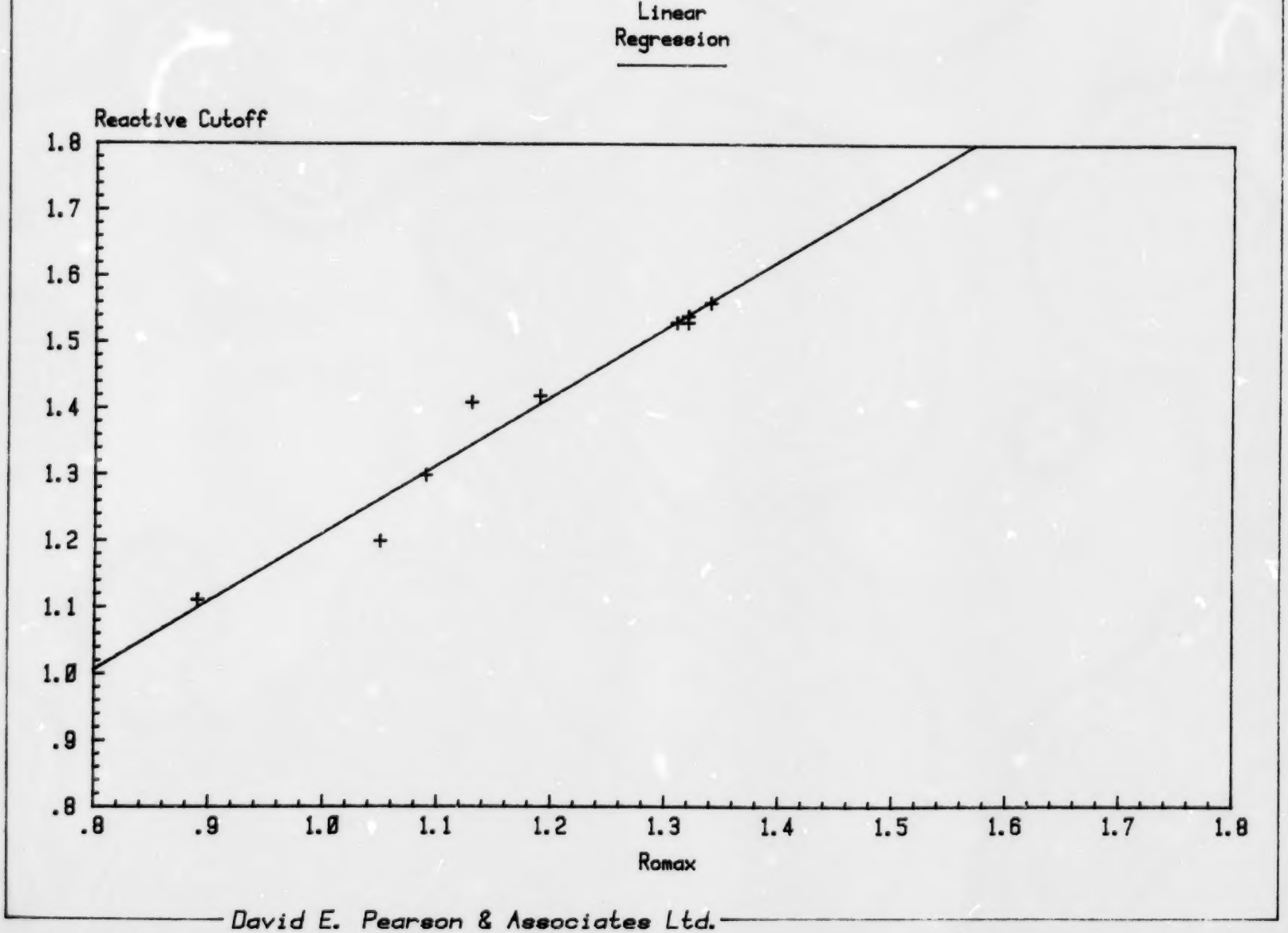
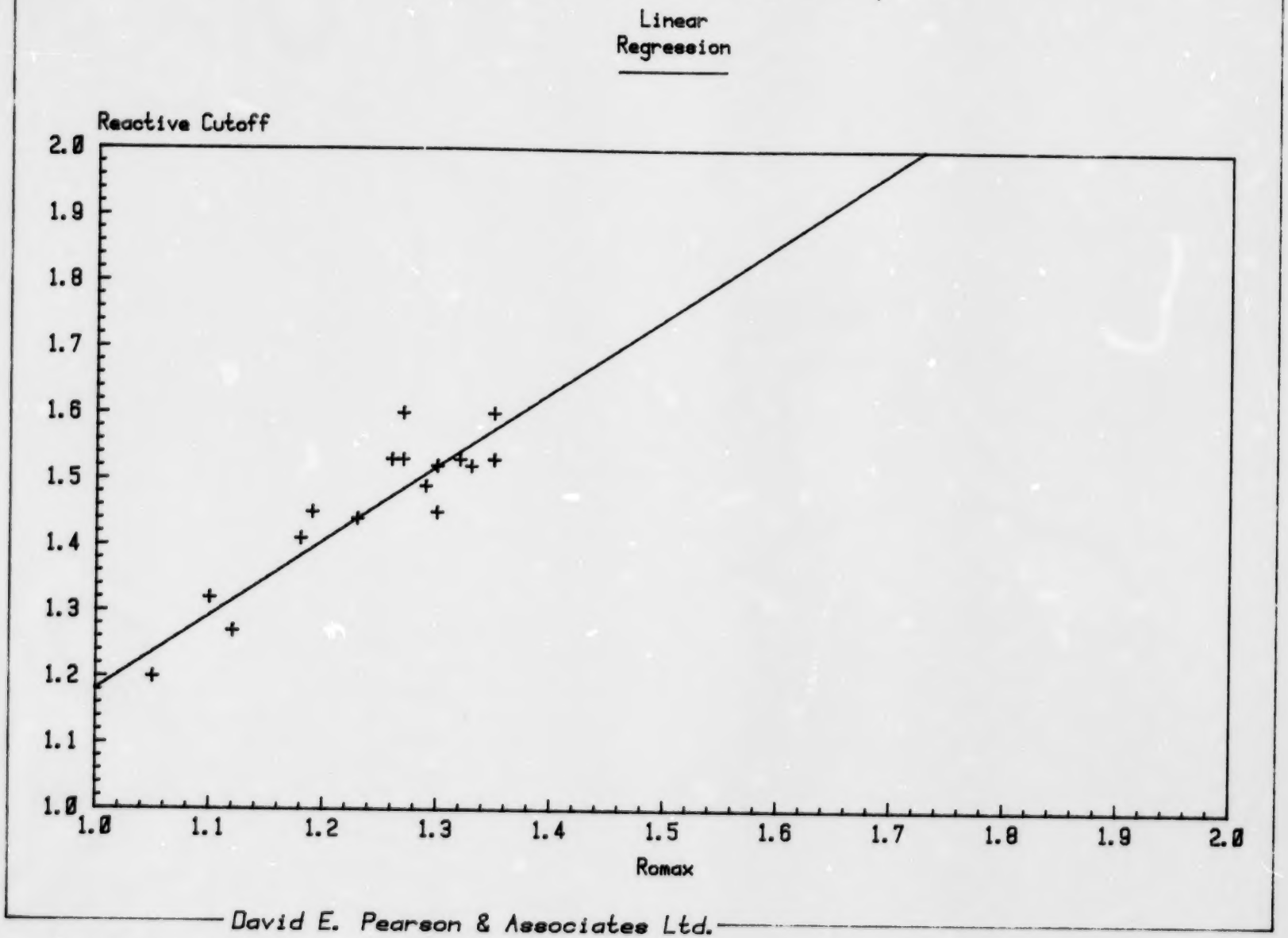


Figure 7

Correlation Romax Vs. Cutoff

Crows Nest Resources' Samples



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correlation coefficient for this line is 0.83.

The slope for this line is given by the equation:-

Reactive Cutoff Value R_o (%) = 1.13($R_o$max) - 0.054

5.3. Semifusinite Reactivity.

Semifusinite reactivity has been computed for each sample as shown in Table 1. A review of these data show that the percentage of reactive semifusinite is not fixed, but is variable from sample to sample.

The mean semifusinite reactivity for the 61 samples is 28.3%, with a standard deviation of 6.3, a standard error of 0.80 and a coefficient of variation of 22.31%. A histogram of the percentage reactive semifusinite for the complete sample suit is shown in Figure 8.

5.3.1. Quintette

The mean percentage reactive semifusinite for the Quintette sample suite is 27.6, with a standard error of 0.82, a coefficient of variation of 16.87%, and a standard deviation of 4.65. The histogram of the percentage semifusinite distribution is shown in Figure 9.

5.3.2. Fording

The mean semifusinite reactivity for the Fording sample suite is 33.3%, with a standard error of 1.71, a coefficient of variation of 15.4%, and a standard deviation of 5.1. The histogram of the percentage reactive semifusinite distribution is shown in Figure 10.

5.3.3. Crows Nest

The mean percentage reactive semifusinite for the Crows Nest sample suite is 28.3, with a standard error of 0.80, a coefficient of variation of 22.3% and a standard deviation of 6.3. The histogram of the percentage reactive semifusinite distribution is shown in Figure 11.

Figure 8

% Reactive Semifusinite

All Samples

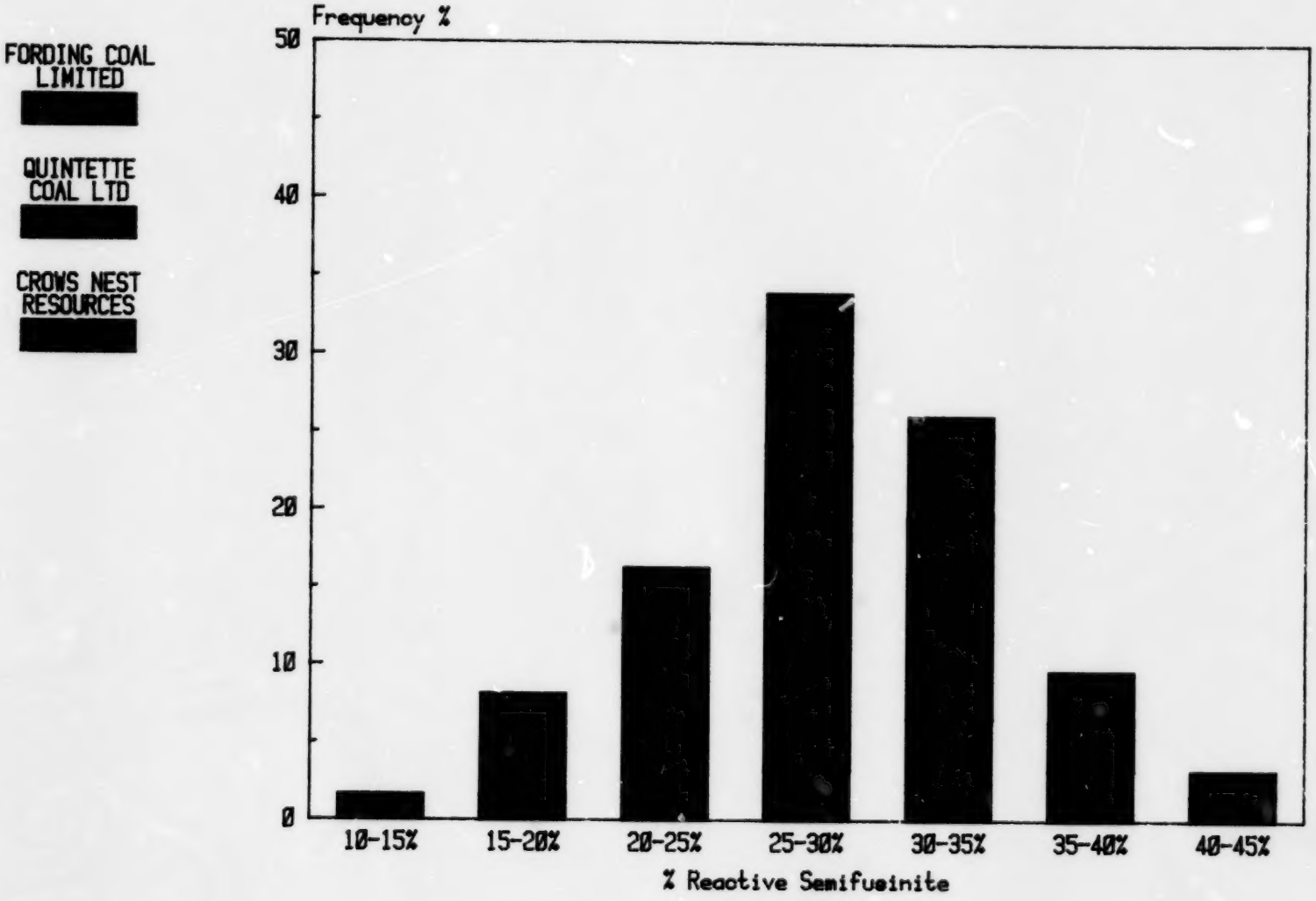

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Figure 9

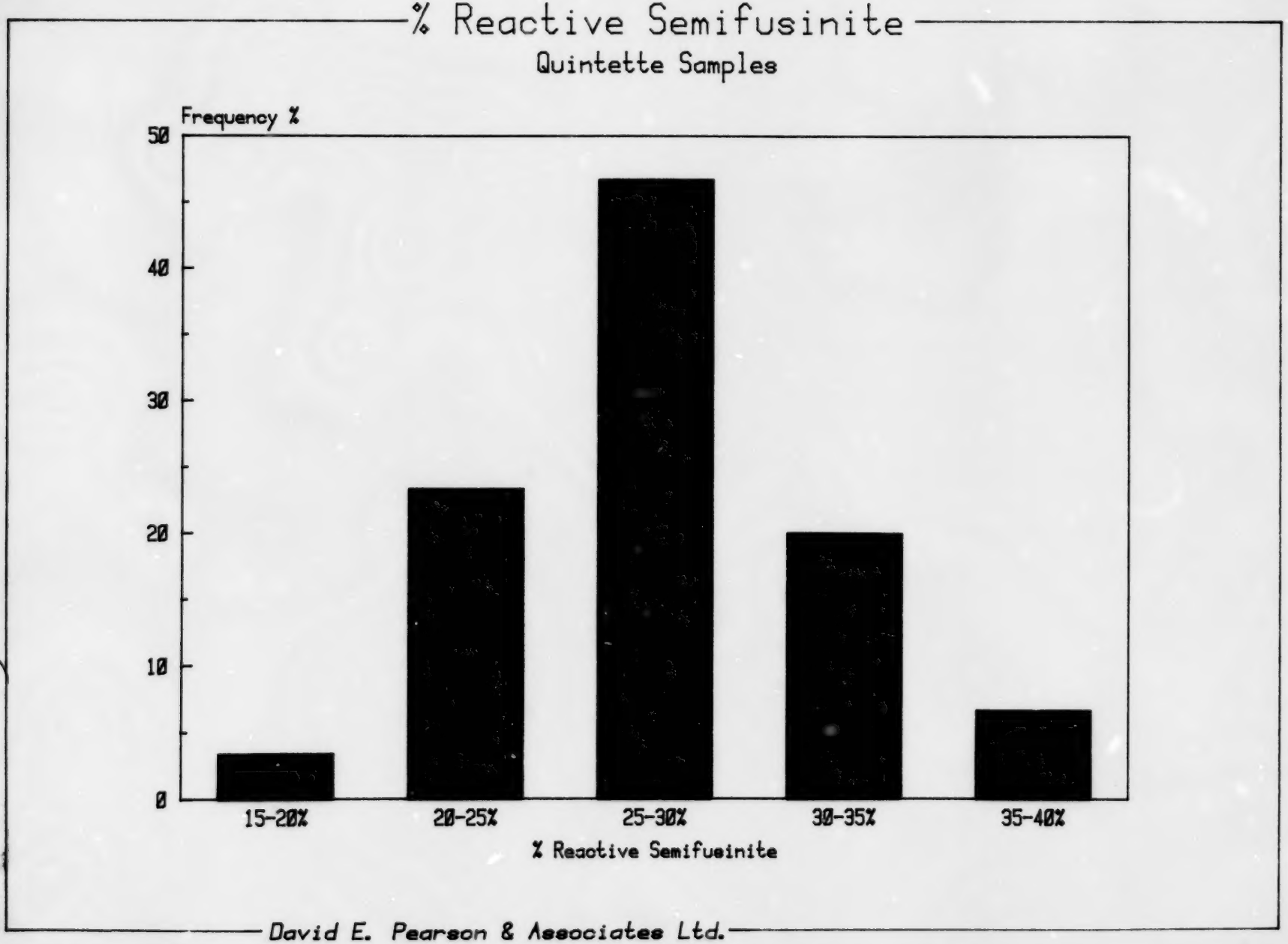
% Reactive Semifusinite
Quintette Samples
Frequency %
50
40
30
20
10
0
15-20%
20-25%
25-30%
30-35%
35-40%
% Reactive Semifusinite
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Figure 10

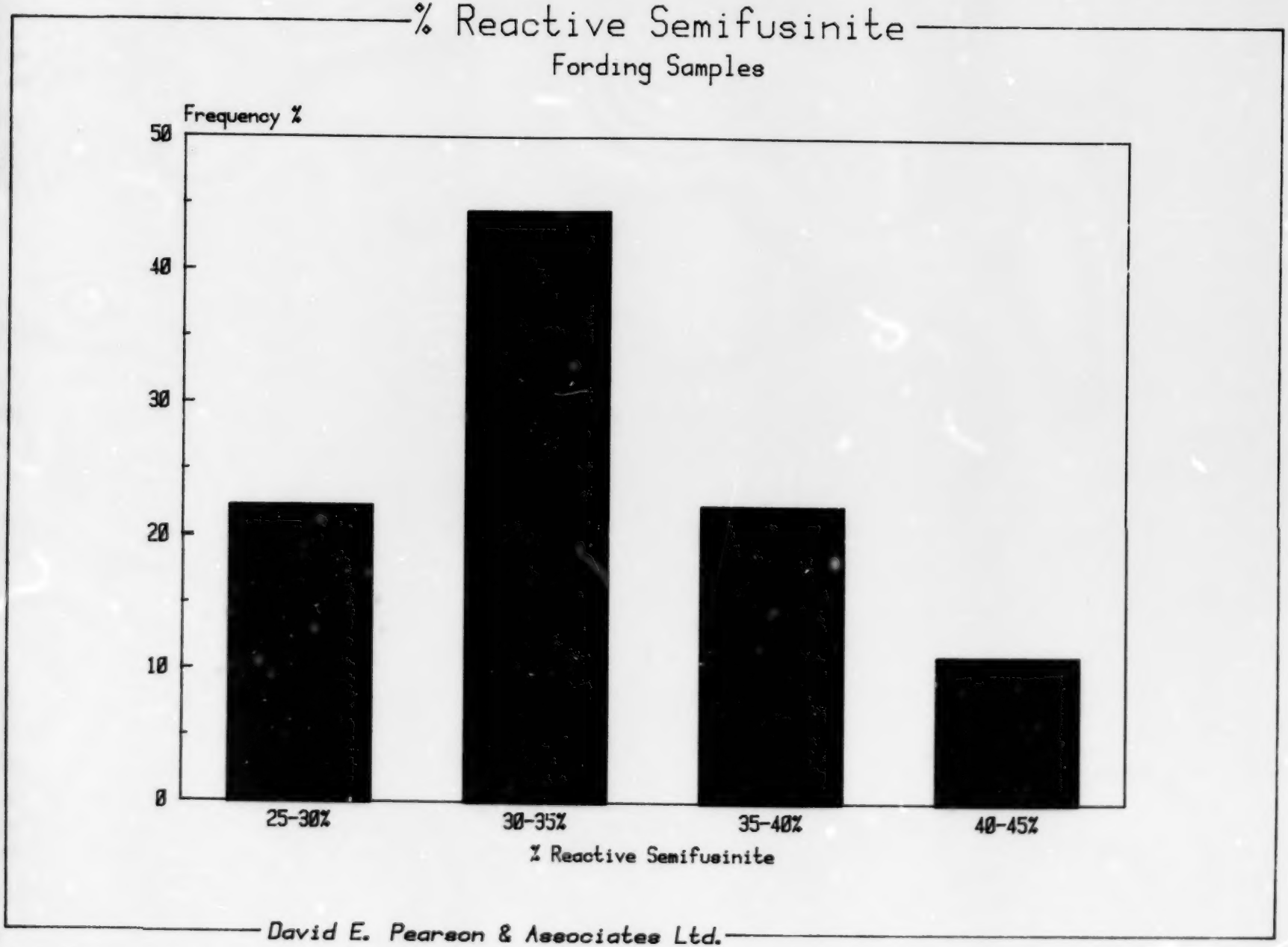
% Reactive Semifusinite
Fording Samples
Frequency %
50
40
30
20
10
0
25-30%
30-35%
35-40%
40-45%
% Reactive Semifusinite
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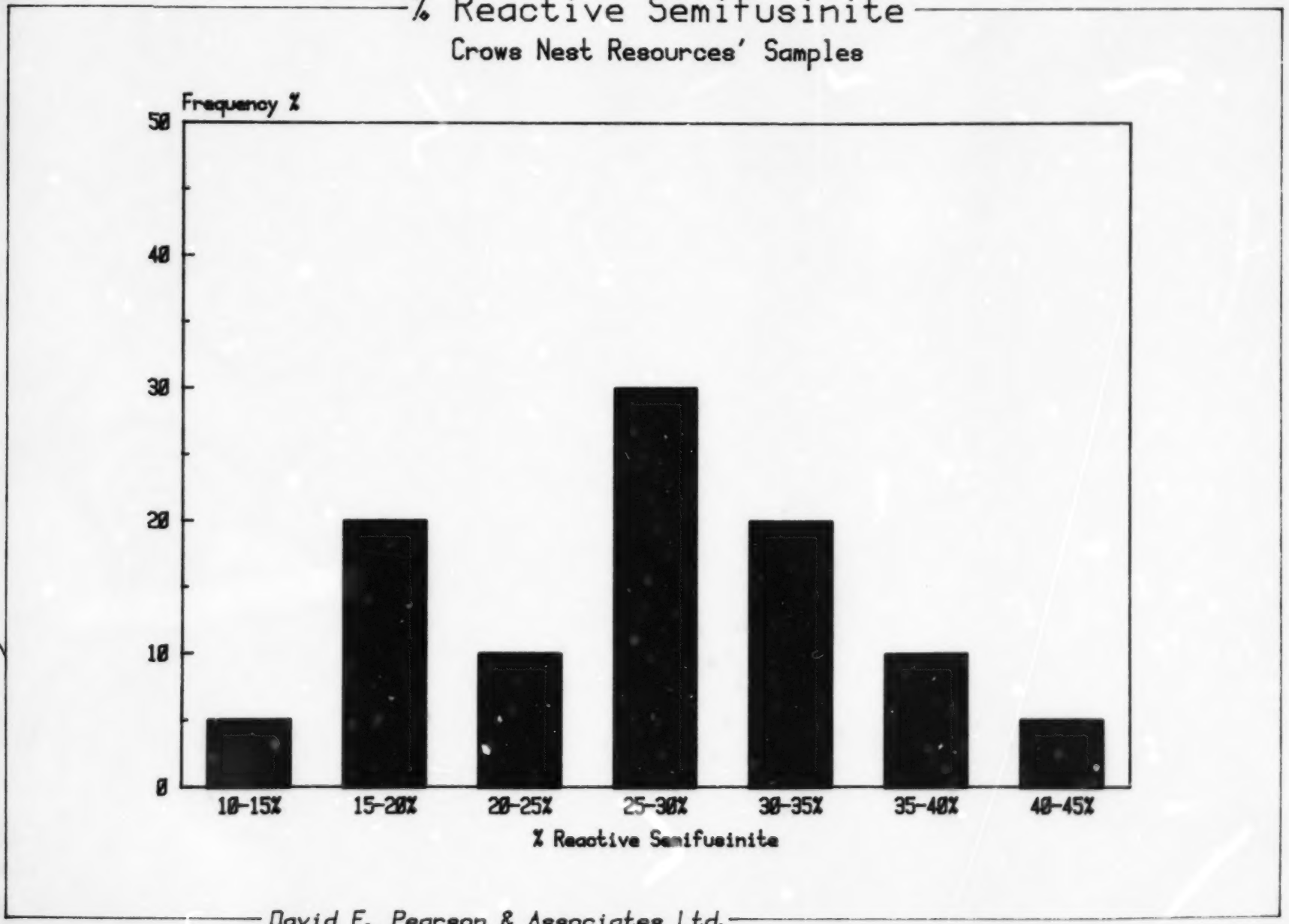
Figure 11


% Reactive Semifusinite
Crows Nest Resources' Samples
Frequency %
50
40
30
20
10
0
10-15%
15-20%
20-25%
25-30%
30-35%
35-40%
40-45%
% Reactive Semifusinite
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6.0. DISCUSSION

6.1. Coal-type Analysis.

Coal-type analysis attempts to separate microscopically recognizable coal particles into inert- and reactive-categories, following the technique of Schapiro, Gray & Eusner (1961), which was developed for Pennsylvanian-age coals. This method considers that together with the easily-recognizable exinites and vitrinites, one-third of the total semifusinites comprise the reactive macerals.

The essence of the Schapiro et al method, is that the proportion of reactive semifusinite is related to the total semifusinite by the following relationship:-

$$R = kT$$

where R = Reactive semifusinite,
k = a constant, semifusinite reactivity, and
T = Total semifusinite.

The Schapiro et al method considers that k, semifusinite reactivity, has a constant value of 0.33, equivalent to 33% of the total semifusinite.

Among Pennsylvanian coals, vitrinite and exinite comprise 80-90%, and the total semifusinite content is often close to 10%, so the reactive portion would be 3.3%. For the purposes of discussion however, let us assume that the proportion of reactive semifusinite is not one third, but is really one-half of the total semifusinites, that is, k = 0.5. In such a circumstance, the total reactives will increase by only 1.7%. The formula above demonstrates that reactive semifusinite will increase as the reactivity increases, but that if the total semifusinite content is low, the increase is proportionally very small and may not be detectable. This explains why the Schapiro et al method can be used successfully with coals that have a large proportion of vitrinite and exinite, i.e. coals with low total semifusinite contents. To test the universality of the Schapiro formula however, requires high semifusinite-content coals, which were not available to the researchers when they developed their method in the 1950's.

In contrast, western Canadian coking coals typically

contain a varying, and much larger proportion of semifusinite. Assume for a moment that we have a coal with 45% semifusinite. If one-half of this semifusinite is reactive, then there is a contribution to the reactive macerals of 22.5%. However, if only 30% is reactive, the contribution is reduced to 13.5%, and the difference between the two is a staggering 9%!

These examples illustrate the two principal pitfalls in the Schapiro & Gray method. The equation above shows that when determining reactive semifusinite there are really only two principal sources of error, namely, k and T. Thus, the pitfalls of the Schapiro et al method are that it assumes:-

1. A fixed proportion of reactive semifusinite, i.e. semifusinite rectivity k, is always equal to 0.33.

2. The correct identification of semi-inert (semifusinite) macerals has been made, i.e. that total semifusinite, T, is the true value.

With a high semifusinite coal, if either of these two values departs from the true, and unknown, values for that coal, then there can be a very pronounced impact on the quality of the petrographic predictions.

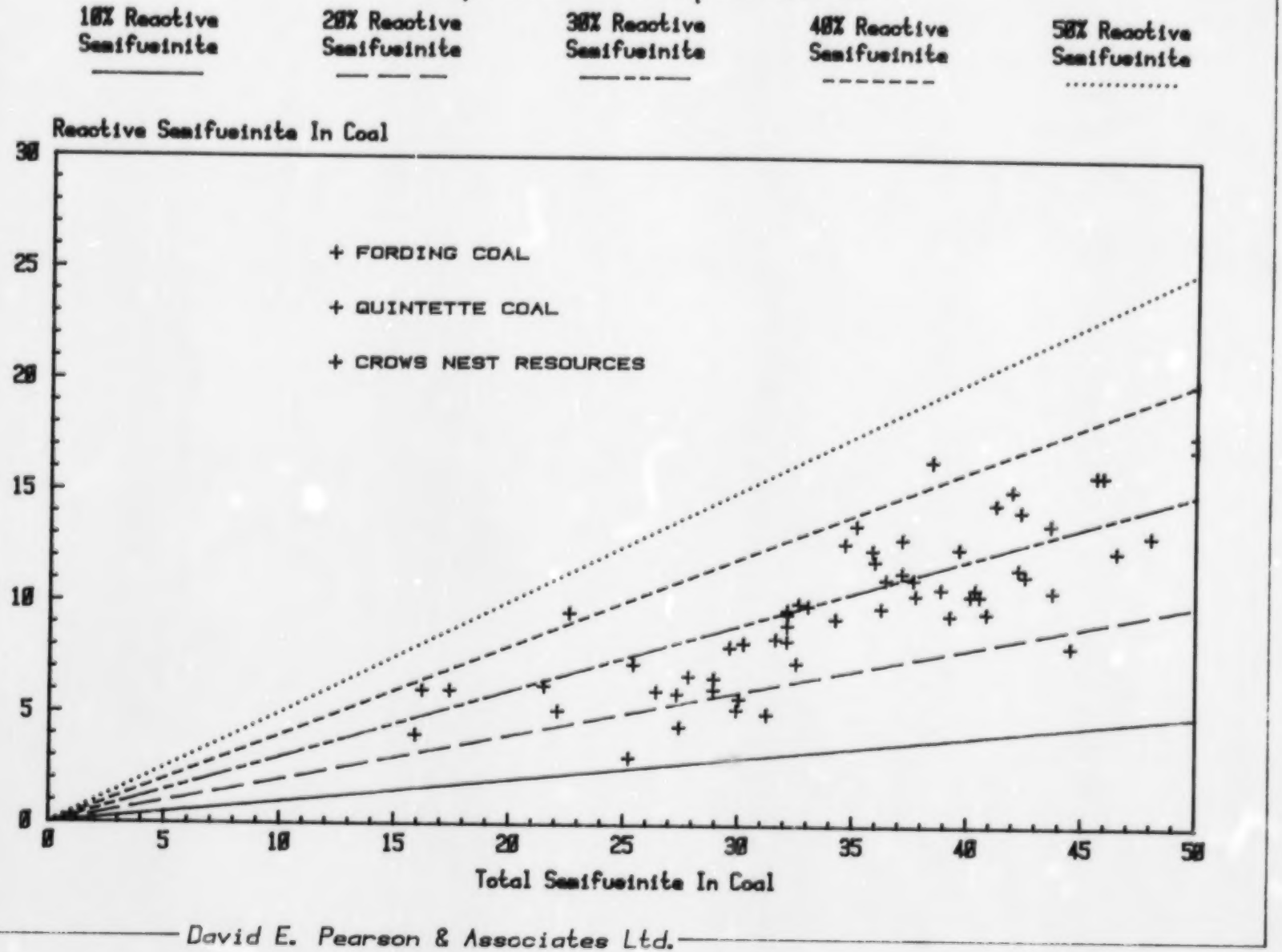
Figure 12, which plots reactive semifusinites versus total semifusinites, displays a series of **semifusinite reactivity lines**, drawn through the origin, for different semifusinite reactivities from 10% to 50% (k=0.1 to k=0.5). Plotted in the diagram are the positions of the 61 coals used in this study using the maceral data contained in Table 1. For each sample, the amount of reactive semifusinite is exactly the amount required to predict the determined coke strength, as calculated on the upper right side of the reflectograms.

Figure 12 shows that to correctly predict the coke strength of the 61 samples used in this study, semifusinite reactivity would have to vary between 12% and 43%. The diagram is clear evidence that **there is not a fixed proportion of reactive semifusinite applicable to all coals.** The mean percentage of reactive semifusinite for the complete suite of samples is 28.3%, close to the 33% as suggested by Schapiro & Gray, but for many coals that simply is not close enough to give a reliable prediction of the coke stability index.

Figure 12

Reactive Semifusinite In Coal

Complete 61-Sample Suite



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The figure confirms that for small total-semifusinite contents (=10%), there is only a 2% difference in the contribution to the total reactive maceral content using semifusinite reactivities of 20% or 40%, which is equivalent to the standard deviation for the total reactive macerals in a 1000-point maceral count of such a coal.

The diagram shows however, that with increasing total semifusinite content, the variations in semifusinite reactivity profoundly effect the reactive semifusinite content, precisely as predicted by the Schapiro et al relationship, R=kT. Therefore, among high (T) total semifusinite coals (typical Western Canadian coals), an incorrect assignment of semifusinite reactivity (k), dramatically affects the predicted coke strength. This explains why the discovery of a coke-strength prediction-technique for high semifusinite coals, that requires a fixed proportion of reactive semifusinite, has, and will continue to elude coal petrographers. Each coal has a unique semifusinite reactivity, which varies even within a single seam.

6.2. Reflectance Method.

The results of this study show that the Reactive Cutoff bears a linear relationship to $R_o$max over the range of vitrinite reflectances examined. In other words, the rank ($R_o$max) of the coal **defines** the value of the Reactive Cutoff. Because of this, the distinction between reactive- and inert-macerals can be made wholly on the basis of random reflectance.

This relationship allows a different method of coal-type analysis to be proposed. Such a method involves measuring the random reflectance of all macerals, and allowing the distinction of reactive- or inert-macerals to be based wholly on the random reflectance according to the equation:-

$$\text{Reactive Cutoff Value } (R_o \text{ random}) = 0.99(R_o\text{max}) + 0.24$$

Using this technique, the reactivity of semifusinite, or any other maceral, is determined directly, and is not assigned later only when the total semifusinite count has been determined. And for practical purposes, **it is no longer neccessary to be able to correctly recognize semi-inert macerals, nor is the proportion of reactive**

semifusinite important.

A similar approach to coal-type analysis has recently been proposed for Australian coking coals, by Diessel (1983). Diessel measured the reflectance of numerous macerals on a freshly exposed coal surface, and on the same, or adjacent surface after carbonization. In this way, the effect of elevated temperatures on individual macerals was determined, and a cutoff value was located on the basis of the level of bireflectance of inertinite in coal and coke.

In theory, the cutoff value determined by Diessel should be the same as the Reactive Cutoff described above. Unfortunately, Diessel measured the maximum reflectance, not the random reflectance, of the macerals he encountered. As a result, his Figure 10, which relates vitrinite $R_o max$ to the cutoff $R_o max$ cannot be directly compared to Figure 7 of this report. Also, from a practical point of view, stage rotation during maceral analysis is very time-consuming, and is rarely done.

In 1967, (Taylor, MacKowsky & Alpern), reported that the semifusinite cut-off was 0.1% to 0.2% above the accompanying vitrinite. This conclusion was based on similar work to that done by Diessel. Tests using coal from Saxon property and Elco property in British Columbia showed that the semifusinite cut-off was 0.2% above the accompanying vitrinite (Koensler 1980). The technique used by Koensler was bench-scale heating, and employed similar apparatus to that used in the Australian experiments. In these instances it was not stated whether the quoted cutoff was based on random or maximum reflectance.

6.3. Comparison of Methods.

Table 1 contains a section on Coke Strength Indices, showing the determined tumbler stabilities and predictions of coke strength based on the Schapiro, Gray and Eusner method and by the Reflectance Cutoff method (described as Pearson method).

Of the predicted coke strength values in this table, 73.4%, using the Reflectance Cutoff method are closest to the tumbler determined value. The remaining 26.6%, which use the Schapiro et al method, are closest to the predicted values.

Using the Reactive Cutoff method, 64% of the predicted tumbler stability indices are within 1 stability unit of the determined values.

Figure 13 shows a correlation between measured and predicted stability using the Reactive Cutoff method (Pearson method). The green line in the diagram is the parity line. The data have a correlation coefficient of 0.835, and are related by the regression equation:-

Tumbler Stability = 0.97(predicted coke strength) + 1.94

Figure 14 shows a correlation between measured and predicted stability using the Schapiro et al method. The green line in the diagram is the parity line. The data have a correlation coefficient of 0.833, and are related by the following linear regression equation:-

Tumbler Stability = 0.95(predicted coke strength) + 1.26

Figure 15 is a histogram showing the difference in stability units between the tumbler-determined coke stability and the predicted coke strength using the Reactive Cutoff (Pearson) method. Figure 16 is a similar histogram using the Schapiro et al method.

7.0. TEST SET OF COALS

At the end of the study, six coal samples were selected by CANMET to see if the technique is applicable to Appalachian coals and low volatile Western Canadian coals, as these coals were absent from the original suite. One of the coals was thought by CANMET to be oxidized. The results of analyses on this test-set are shown in Table 2.

From these data, it would appear that Sample #1193 is the one regarded by CANMET as oxidized.

8.0. CONCLUSIONS

1. It has been demonstrated that for each of the 61 samples studied, a random reflectance value exists that separates reactive- from inert-macerals. This value is referred to as the **Reactive Cutoff.**

Figure 13

Measured Vs. Predicted Stability

Pearson Method

Parity

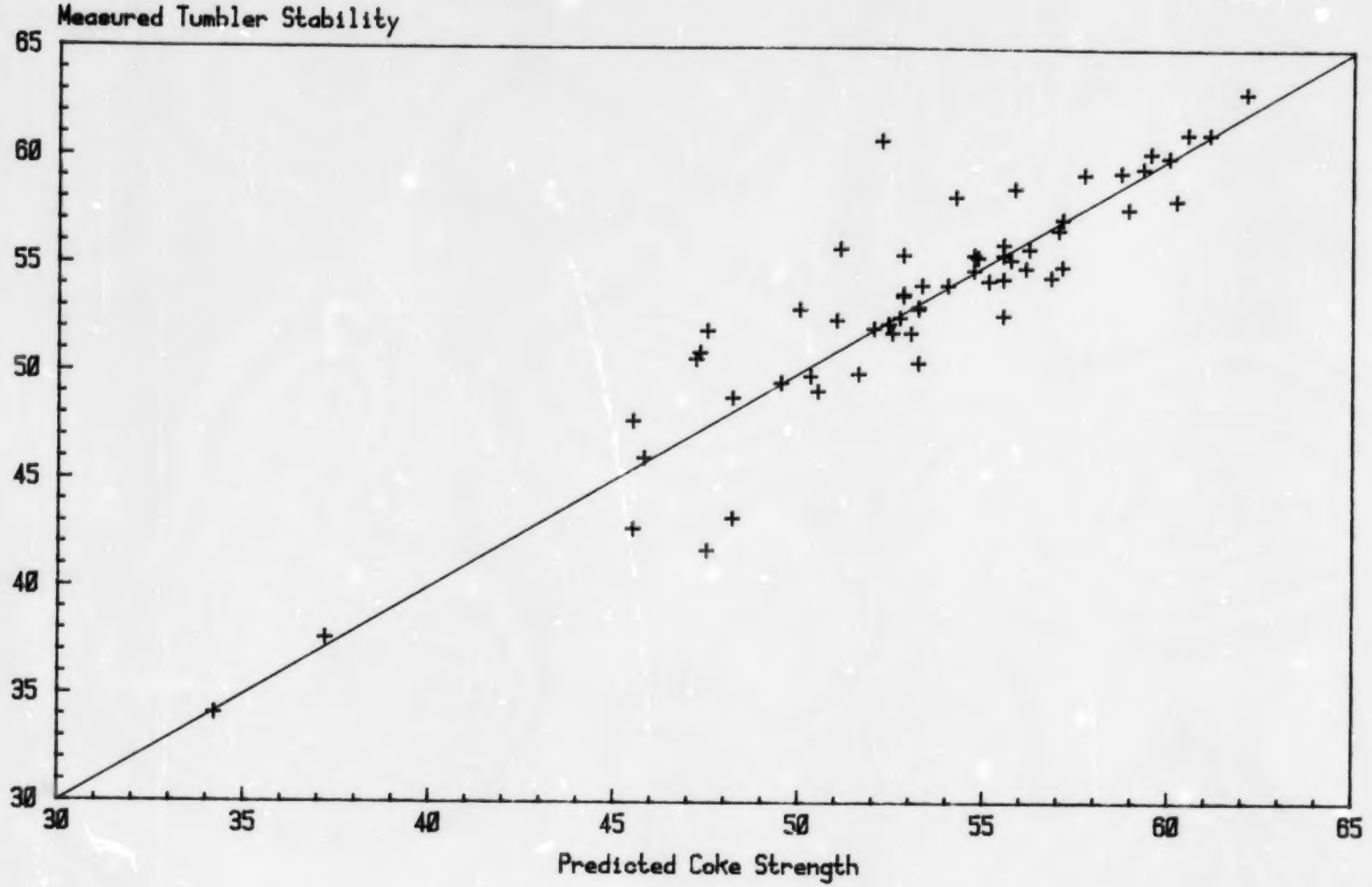

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Figure 14

Measured Vs. Predicted Stability

Schapiro et al Method

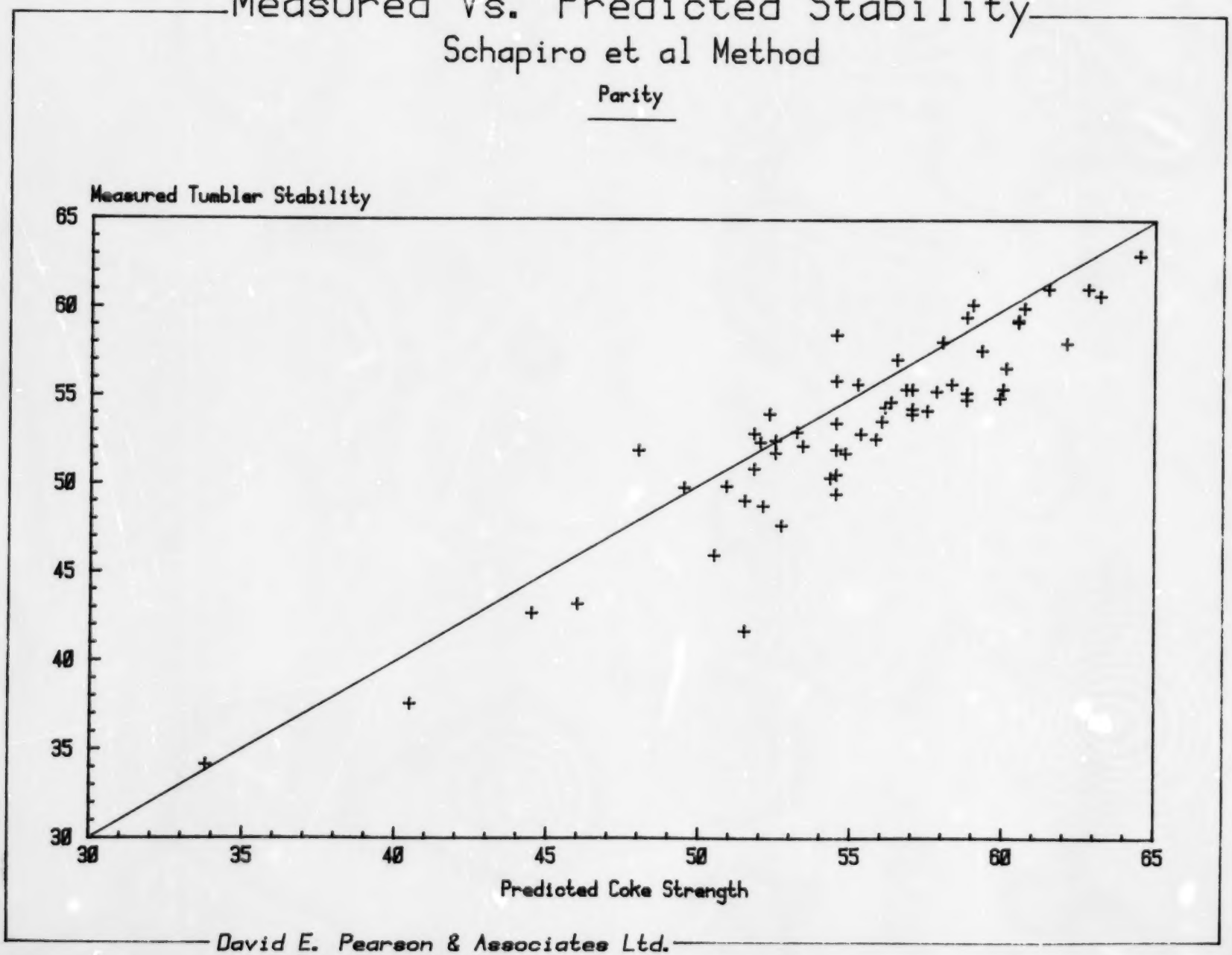

Figure 15

Predicted Vs. Measured Stability

Difference Using Pearson Method

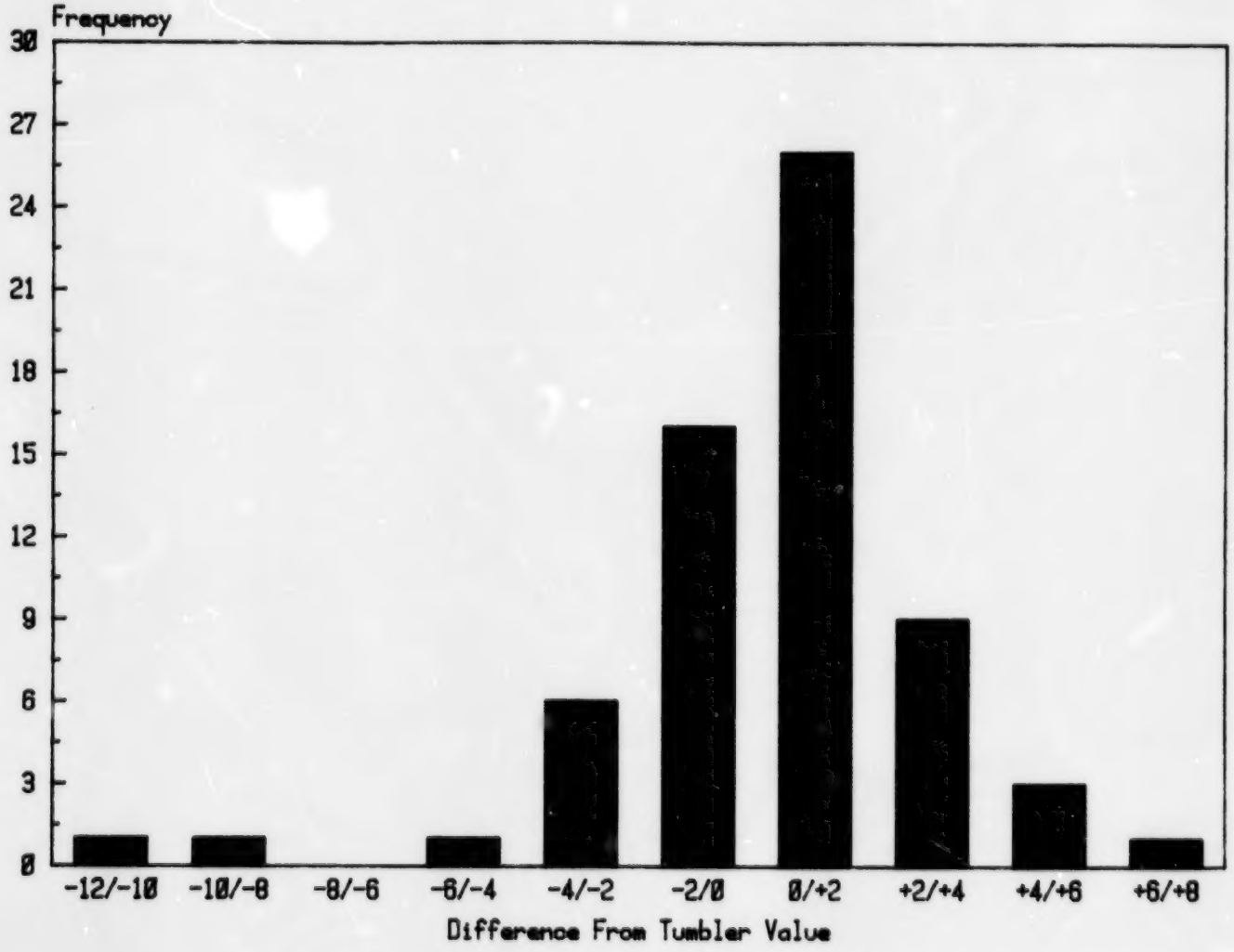

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Figure 16

Predicted Vs. Measured Stability

Difference Using Schapiro Method

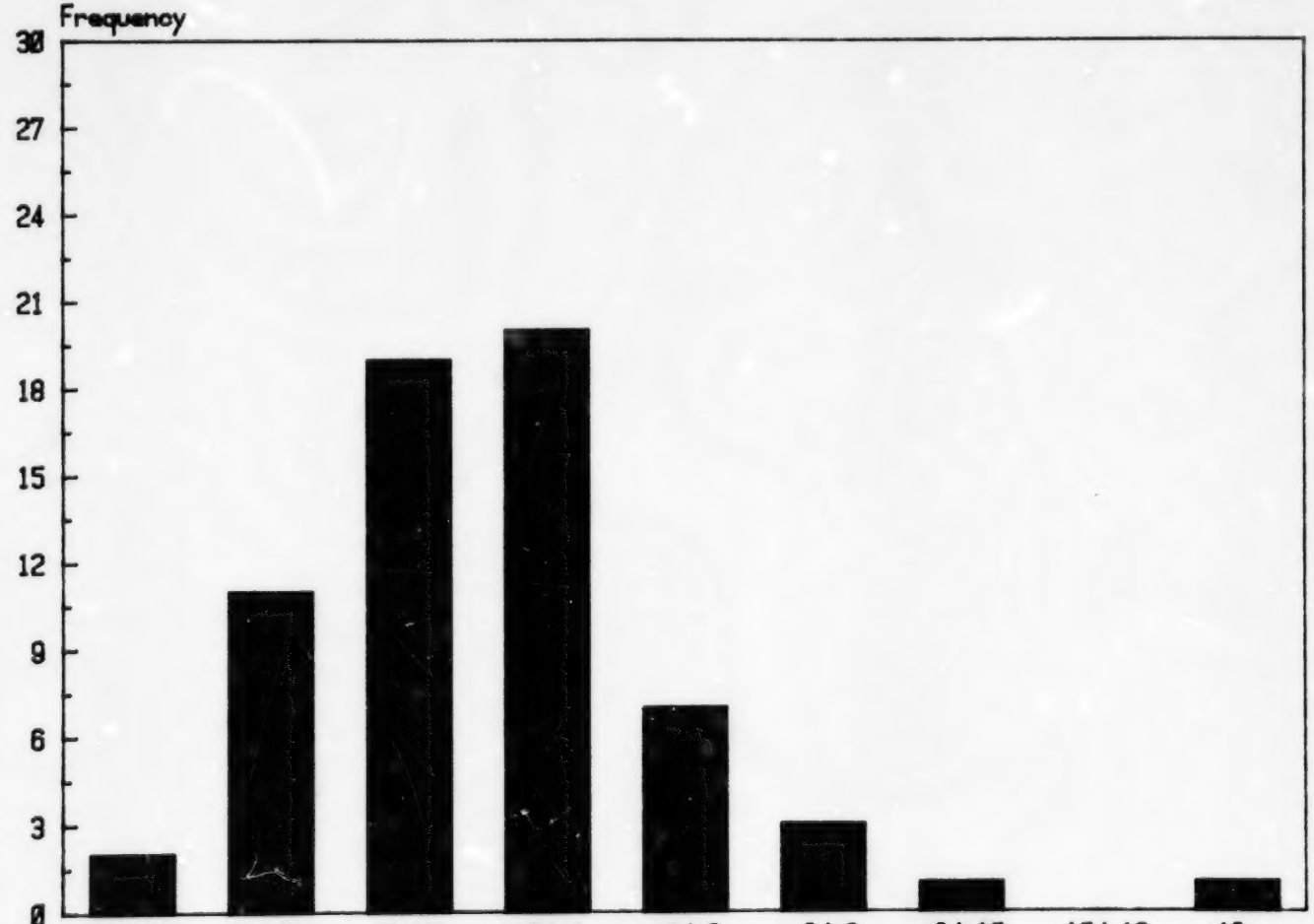

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Table 2

CANMET Sample #	1172	1176	1193	1446	1426	1826
Reflectance Analysis						
V-7...			3		1	
V-8...	4	1	20		27	
V-9...	24	28	59		64	
V-10..	57	57	14		7	
V-11..	15	14	4		1	
V-14..						6
V-15..				7		47
V-16..				44		40
V-17..				45		6
V-18..				4		1
$R_o$max.	1.03	1.04	0.95	1.69	0.93	1.59
R_o random	0.83	0.85	0.80	1.51	0.79	1.46
Maceral Analysis						
Vitrinite	77.1	69.9	66.9	75.0	66.2	58.5
Exinite	6.3	5.3	8.2	0.0	3.2	0.0
Reactive SF	4.4	4.8	2.9	4.8	4.4	7.7
Total SF	12.0	16.7	18.2	18.5	23.9	34.2
(% SF Reactivity)	36.6	28.7	18.9	25.9	18.4	22.5
Inert SF	7.6	11.9	15.3	13.7	19.5	26.5
Macrinite	0.6	0.7	0.8	0.6	1.4	1.1
Inertodet.	0.7	1.7	1.2	1.6	0.3	1.2
Fusinite	1.0	1.9	0.6	0.6	1.6	0.9
Min. Mat. (Parr)	2.0	3.4	4.1	3.7	3.1	4.1
Other	0.3	0.4			0.3	
Total Inerts	12.2	19.9	22.0	20.2	26.2	33.8
Reactive Cutoff	1.25	1.26	1.17	1.91	1.15	1.81
Schapiro Inerts	12.6	19.2	18.8	18.8	22.6	30.1
Coke Strength Indices						
Tumbler Stability	38.1	49.4	28.0	57.8	45.9	46.3
Schapiro Method	38.0	48.9	41.5	61.0	43.7	54.1
- difference	-0.1	+0.5	+13.5	+3.2	+2.2	+7.8
Pearson Method	36.9	49.9	44.9	59.5	45.9	49.4
- difference	-1.2	+0.5	+16.9	+1.7	00.0	+3.1

2. It has been found that over the vitrinite reflectance range studied, there is a strongly correlative linear relationship between $R_o max$ and the random reflectance value of the Reactive Cutoff (R^2=0.92). The Reactive Cutoff value is defined by the following equation:-

$$\text{Cutoff random } R_o \ (\%) = 0.987(R_o max) + 0.236$$

3. The proportion of reactive semifusinite that was added to the reactive macerals to correctly predict the previously determined coke strength was not 33% as advocated by the Schapiro, Gray & Eusner method, or 50% as advocated by the Carr & Jorgensen method. It was found that in the 61-sample suite, the proportion of reactive semifusinite varied from 12% to 43%.

4. It is therefore concluded that a coke-strength prediction technique that requires a fixed proportion of reactive semifusinites is unlikely to prove universally applicable among Inertinite-rich coals. Such a method will enjoy various levels of success **only where the proportion of total semifusinites is low.** It is for these latter coals that the Schapiro-Gray method was designed.

5. For any coal, the Reactive Cutoff can be computed from $R_o max$, and based on this, the distinction between inert- and reactive-macerals can be made. **It is no longer neccessary to be able to recognize semifusinite macerals.**

6. Maceral analysis based on the Reactive Cutoff method renders unimportant any discussion of the percentage of reactive semifusinite.

9.0. REFERENCES

Carr, A.J. and Jorgensen, J.G.,
1975: An Estimate of the Effective Reactive/Inert Ratio of Semi-Fusinite in Western Canadian Coals. E.M.R. CANMET Report 75-141, 12p.

Diessel, C.F.K.,
1982: On the Reactivity of Inertinite Macerals in Coal during Carbonization. Research Report #1. Dept. of Geology. Univ. Newcastle (Australia). 47p.

Diessel, C.F.K.,
1983: Carbonization reactions of inertinite macerals in Australian coals. FUEL(Lond.) Vol. 62, p. 883-892

Koensler, W.,
1980: Das Verhaltens des Inertinits westkanadischer Kreidekohlen bei der Verkokung. Doctoral dissertation. Rheinisch-Westfalischen THS. Aachen. 118p

Pearson, D.E.,
1980: The Quality of Western Canadian Coking Coal. Bull. Can. Inst. Min. Met. v. 73, no. 813, p. 70-84.

Schapiro, N., Gray, R.J. and Eusner, G.R.,
1961: Recent Developments in Coal Petrography. Blast Furnace, Coke Oven and Raw Materials Committee, Proc. Vol. 20. p. 89-112.

Taylor, G.H., MacKowsky, M-Th. and Alpern, B.,
1967: The Behavior of Inertinite during Carbonization. FUEL(Lond.). Vol.46. p.431-440.

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